N92-23281

LONG DURATION EXPOSURE FACILITY--A GENERAL OVERVIEW

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INTRODUCTION

The Long Duration Exposure Facility (LDEF) is a large, low-cost, reusable, unmanned, free-flying spacecraft which accommodates technology, science, and applications experiments for long-term exposure to the space environment. The LDEF was designed and built by the NASA Langley Research Center (LaRC) for NASA's Office of Aeronautics and Space Technology. Specifically, the LDEF was designed to transport experiments into space via the Space Shuttle, to free fly in Earth orbit for an extended period, and be retrieved on a later Shuttle flight allowing experiments to be returned to Earth for postflight analysis in the laboratory. The LDEF with a full complement of experiments was placed in Earth orbit in April 1984 by the Space Shuttle Challenger and retrieved from orbit in January 1990 by the Space Shuttle Columbia.

A general overview of the LDEF, its mission, systems, experiments, and operations is covered in the following sections. Excerpts from various NASA documents (refs. 1 to 7) are extensively used.

MISSION SUMMARY

The Space Transportation System STS 41-C mission whose objective was to deploy LDEF and then retrieve, repair, and redeploy the Solar Maximum Mission satellite, was launched from Kennedy Space Center (KSC) on April 6, 1984. The LDEF was deployed in a 28.5° inclination essentially circular orbit of 257 nautical mile altitude by the Shuttle Challenger on April 7, 1984. It was planned to retrieve LDEF about 1 year later; however, Shuttle manifesting problems and later the Challenger accident together resulted in an extensive delay. The LDEF was retrieved some 69 months after launch at an altitude of 179 nautical miles. Only about 2 months of orbit lifetime remained at the time of retrieval.

On the second day of the deployment mission the remote manipulator system (RMS) was used to activate the experiment initiate system (EIS) while LDEF was still berthed in the cargo bay. After confirmation that the initiate was successful, the RMS was used to lift the LDEF from the cargo bay and place it in a preferred attitude for release and free flight. Gravity gradient torques maintained the LDEF in a position in which the axis of minimum moment of inertia was aligned with the local vertical. This resulted in one end of LDEF always pointing towards the center of the Earth and one end always pointing out in space. Coupling torques resulting from small preestablished differences in the transverse moments of inertia stabilized the facility about the longitudinal axis and resulted in one of the 12 sides always pointing forward in the direction of

travel. This established a leading side and a trailing side of LDEF. Figure 1 illustrates the LDEF orientation in orbit.

A viscous magnetic rate damper was mounted on the LDEF interior structure to accelerate the damping of any unwanted motions at the time of deployment. A photograph of the damper after deintegration is shown in figure 2. After deployment (see fig. 3) no unwanted motions were apparent. The LDEF remained in a stable attitude during the 69-month mission.

The LDEF retrieval mission was launched on January 9, 1990. Rendezvous with the LDEF was completed and LDEF retrieved on January 12. Figure 4 is a photograph of the LDEF minutes before capture by the RMS. To establish the condition of experiments prior to the reentry the flight crew used the RMS to maneuver the LDEF for an extensive photographic survey of the LDEF and each experiment tray. The LDEF was then berthed and the remainder of the mission completed with a landing at Edwards Air Force Base on January 20. The Columbia with LDEF still in the cargo bay was ferried from Edwards to KSC, landing on January 26. The LDEF was removed from the orbiter in the Orbiter Processing Facility (OPF) and moved to the Spacecraft Assembly and Encapsulation Facility II (SAEF II) for several months of deintegration operations. Operations were completed and the facility structure was placed in storage at KSC in mid-May 1990.

LDEF DESCRIPTION

Structure

The LDEF is a 12-sided, 14-foot diameter, 30-foot long aluminum open grid frame. The structure is configured with 72 equal-size rectangular openings on the sides and 14 openings on the ends (six on the Earth-facing end, and eight on the space-facing end) for mounting experiment trays. The LDEF total weight is approximately 21,400 pounds, made up of structure and systems weight of 8,900 pounds and trays and experiment weight of 12,500 pounds.

A photograph of the LDEF structure mounted on the LDEF Assembly and Transportation System (LATS) is shown in figure 5. The LATS is a combination work and transportation platform system which can rotate the LDEF for the installation and for removal of experiment trays.

The LDEF structural configuration and the identification of experiment locations is shown in figure 6. The 12 sides of the structure are numbered rows 1 through 12 in a clockwise direction when facing the end with the support beam (the Earth-facing end in orbit). The six longitudinal locations are identified alphabetically as Bay A through Bay F starting at the end with the support beam. A tray location is designated by the bay and Row A-1, B-5, F-8, etc. The Earth-facing end is designated by a G identifier and the locations have even-number clock-position identifications (G-12, G-2, G-4, G-6, G-8, and G-10). The space-facing end is designated by an H identifier, and the locations follow a similar convention (H-12, H-1, H-3, H-5, H-6, H-7, H-9, and H-11).

The LDEF is attached to the Shuttle by four trunnions and a keel pin. These are identified in figure 6. The main loads of the LDEF are transmitted through the two side support trunnions on the center ring. The keel pin on the bottom of the center ring gives lateral support. The end support beam attached to one end reacts vertical loads and has the freedom to pivot about its center pin joint.

Experiment Trays

LDEF experiments are self contained in trays that are clamped to the facility structure. The LDEF has 72 peripheral and 14 end experiment trays. To accommodate the diverse experiment requirements and characteristics, the trays are of five standard sizes: 3-inch deep, 6-inch deep, and 12-inch deep peripheral trays and 6-inch deep and 12-inch deep end trays. All of the trays are constructed of 6061-T6 anodized aluminum sheet of either 0.063 or 0.125-inch thickness, riveted to a frame made of 6061-T6 aluminum extrusions and angles. Figure 7 is a photograph of the three sizes of peripheral trays.

The structural members which form the tray bottoms provide the bolt hole pattern for attaching the experiments. These members divide the tray bottoms into six equal rectangles for the peripheral trays and four equal squares for the 14 end trays.

The rectangles establish a preferred configuration for experiments to fit either 1/6, 1/3, 2/3, or a full peripheral tray. The squares allow experiments to occupy 1/4, 1/2, 3/4, or a full end tray.

Each peripheral tray is attached to the LDEF structure by eight clamp assemblies and each end tray is attached by 12 clamp assemblies. Each clamp is held by three stainless steel bolts that fasten directly to the facility structure. A cross section of a clamp assembly and the arrangement of clamps around the trays is shown in figure 8. The clamp bolts are torqued sufficiently at tray installation to prevent motion between the tray flanges and the facility structure.

Some of the tray clamps had white dots (discs) painted on them (see fig. 9) as a visual aid in attempting to measure spacecraft motions (pitch, roll, and yaw) from video and photographs made of the LDEF immediately after deployment. The dots were made of Chemglaze A276 white paint and Chemglaze Z306 black paint.

The bottoms of all tray frames and the sides of all tray walls facing the interior of LDEF were painted with Chemglaze Z306 polyurethane black paint for thermal control.

Experiments were integrated into trays and each fully assembled tray was vibration tested to assure flight safety. Trays were shipped to KSC in sealed or protective containers and integrated with the LDEF facility under Class 100,000 clean room conditions. With the exception of an electrical connection for an on/off signal from the EIS for those trays with active electronic systems, there is only a mechanical interface between experiment trays and the LDEF facility. The experiment trays are standard NASA LaRC-qualified hardware items provided to experimenters for use in integrating their experiments.

Experiment Power and Data System

The experiment power and data system (EPDS) is designed to provide data collection and storage for experiments which have this requirement. The EPDS consists of a data processor controller assembly (DPCA), a magnetic tape module (MTM), and a primary battery source. The DPCA is hardwire programmable by the experimenter and can accommodate a variety of data collection needs. The system operates from primary batteries, and designs were selected which minimize power requirements. The system is primarily intended for the experiment which requires a number of measurements a few times per day over a 9- to 11-month period. Data from the experiment can be a mix of high- and low-level analog, and parallel and serial digital data. The MTM provides storage for about 14 megabits of data. The EPDS utilizes one 7.5-volt and one 12-volt lithium sulfide dioxide (LiSO2) battery.

The EPDS is suitable for mounting in a 6-inch or deeper tray. A block diagram of an EPDS is shown in figure 10. Figure 11 is a photograph of an EPDS mounted in an LDEF experiment tray. Seven (7) EPDS units were flown.

Experiment Environmental Control System

The experiment environmental control canister (EECC) is an automated experiment container capable of opening and closing during the flight of LDEF. The unit provides a means of maintaining a clean, low-pressure, or inert gas environment while closed during ground operations, with the capability to open and expose the experiment to the space environment while in orbit. Five of these systems were flown on LDEF.

A photograph of the EECC assembly mounted in a tray is shown in figure 12. Each utilized 1/3 of a peripheral 6-inch deep experiment tray. An aircraft pressure fitting serves as a vacuum purge valve and allows evacuation of the closed canister by standard laboratory vacuum pumping techniques. The door of the canister uses a Viton rubber O-ring for the seal.

A timer-controller provides the logic for opening and closing the canister. The circuitry within the timer-controller contains two variable timers and a series of switches which control the electrical power for the drive motor. The LDEF EIS starts both timers which generate the signal to open the drawer and later the signal to close the drawer. An opening time of 1 hour to 4000 hours can be selected while a closing time of 2 hours to 8000 hours is available after receipt of the "on" signal from the EIS.

A 26-pin vacuum-sealed connector provides access to the experiment. The leads from the door-mounted connector mate with a flexible interconnecting cable which terminates in a 34-pin chassis connector bottled to the supporting structure of the canister. For those experiments requiring electrical access, the LDEF Project provides the mating half of the chassis connector.

Standard LDEF battery modules provide the 28-volt and 7.5-volt power required to power the EECC.

Experiment Initiate System

The EIS is that system which will send a turn on (set) or a turn off (reset) signal to each experiment when the microswitches located on the rigidize sensing grapple fixture tray are activated. Figure 13 is a schematic of the EIS system. The system consists of two 28-volt lithium sulphur dioxide batteries, four microswitches, an experiment initiate box (EIB), experiment latching relays, six status indicators, and associated wiring. A photograph of the batteries and the EIS mounted on the center ring frame of LDEF is shown in figure 14. The EIS provides for the application of primary power to electrically operate experiments by generating "set" and "reset" current pulses which operate latching relays within the experiments. The status indicators located in the C-10 tray will be white to indicate "set" (on) or black to indicate "reset" (off).

The EIS is self contained and powered by two LiSO2 batteries; it has no electrical interface with the Shuttle. The EIS contains CMOS integrated circuits and discrete electronics parts. The individual "set" and "reset" current pulses to experiments are generated by separate current-limited semiconductor driver circuits. The operating sequence has a battery preconditioning pulse that preloads the battery prior to the generation of the experiment relay pulses.

The EIS is designed to be activated prior to deployment while still latched in the bay, and later after retrieval and LDEF has been latched in the bay. The initiate sequence, shown in figure 15, is started by rigidizing the end effector on the rigidize sensing grapple fixture in tray C-10. The movement of the grapple spike (center post) on rigidization operates the microswitches which energize the initiate system. This starts the $\Delta T1$ delay counter, which permits "set" pulses to be sent to the experiment initiate relays $\Delta T1$ minutes later. If the end effector is detached prior to $\Delta T1$ delay terminal count, the system deenergizes without sending any pulses. In the initiate sequence noted in figure 16, $\Delta T1 = 2.5$ minutes, and $\Delta T2 = 27$ minutes.

The system status indicators shown in figure 16 change from black to white to indicate that the EIS has been activated. The system is designed to change from white to black when the EIS is deactivated at the end of the mission. However, due to the extended mission, the EIS system was not deactivated at LDEF retrieval. This decision was based on the desire to study the EIS in the state in which it had remained for the 69-month mission.

Grapple Fixtures

The LDEF has two grapple fixtures each located in 2/3 of a 6-inch-deep experiment tray. These fixtures are standard Space Transportation System (STS) hardware items provided by the NASA Johnson Space Center (JSC) and serve as the interface between the LDEF and the Shuttle RMS. A standard grapple fixture is located in tray C-1 and a rigidize sensing grapple fixture is located in tray C-10.

The standard grapple fixture in tray C-1 is used for deployment and retrieval of the LDEF by the RMS. A photograph of this fixture is shown in figure 17. The chevron painted in the bottom of the tray is a visual aid for the STS crew to use in proximity operations for LDEF retrieval. The grapple target on either fixture is a visual aid for the RMS operator's use in positioning the end effector over the grapple spike for capture.

The rigidize sensing grapple fixture shown in figure 16 differs from the standard fixture in that the grapple spike is spring loaded and will move approximately one inch during the RMS end effector rigidization. This feature allows this fixture to be utilized as an "on"/"off" switch for the EIS. The movement of the grapple spike shaft activates microswitches in the EIS curcuit. EIS state ("on" or "off") indicators are located near the grapple target in view of the RMS wrist camera. The rigidize sensing grapple fixture is activated by the RMS while the LDEF is latched in the Shuttle cargo bay.

Batteries

The lithium/sulphur dioxide (LiSO2) batteries used on LDEF were developed by LaRC to meet strict performance and safety requirements. The batteries were provided in three nominal capacities: 7.5-, 12-, and 28-volts. A 7.5-volt battery provided power to each EPDS data electronics, a 12-volt battery provided power for each tape recorder, and batteries of each capacity were used as required to power experiments. The battery cells were enclosed in hermetically sealed boxes with approximate dimensions of 6.5 in. x 11.5 in. x 2.5 in. A photograph of the components of a typical battery is shown in figure 18(a). A photograph of a typical battery installation on the back of an experiment is shown in figure 18(b).

Other types of batteries were used on two experiments. Nickel cadmium (NiCd) batteries were used on the Low Temperature Heat Pipe Experiment in tray F-12, and lithium carbon fluoride (LiCF) batteries were used on the Thermal Control Surfaces Experiment located in tray A-9.

Thermal

The LDEF thermal design is completely passive relying on surface coatings and internal heat paths for temperature control and equalization. The LDEF is a cylindrical structure which is open on the interior. The stable altitude of LDEF, one end Earth pointing and a leading and trailing side, resulted in one side facing the Sun or space for extended periods of time. All interior experiment and structure surfaces are painted with an emissivity black paint, Chemglaze Z306 (see fig. 19), to maximum radiation coupling across the facility and to minimize the thermal gradients around it.

The primary means of achieving temperature control of the average internal temperature of LDEF and of experiments is by the selection and placement of experiments and by selecting properties of thermal control coatings. Various types of experiments were placed in a checkerboard arrangement to equalize thermal properties over the surfaces of LDEF. The average internal temperature (defined as the mean average temperature of the internal surface of the experiments) is a result of the heat flow through all the experiments. The goal was to maintain this interior average temperature between 10°F and 120°F to provide temperatures compatible for batteries, electronic systems, and experiment special needs.

The experimenters thermally designed their experiments and trays within the LDEF-supplied guidelines. The experiment thermal boundary conditions are defined in terms of the external flux, the internal average radiation temperature, and the temperature of the structure where the tray is mounted. Experiments can be subjected to different thermal environments depending upon their placement on the LDEF and by the option of coupling radiatively to the interior average temperature and/or to space. The tray is considered part of the experiment and the boundary is assumed at the LDEF structure/tray interface.

The prelaunch, launch, and orbital environments in the Shuttle bay are maintained at temperatures less extreme than the free-flying on-orbit environments by means of mission constraints such as time limits and attitudes. The heat soak and resultant temperature increase after landing is maintained by preconditioning the large mass of LDEF prior to reentry and by ground purge cooling after touchdown.

Ground Support Equipment

The LDEF was mounted on its LATS for all ground operations from initial fabrication through the integration and again during deintegration at KSC. The LATS is a specially designed transportation system which allows the LDEF to be mounted on a spindle pin in each end and rotated in a "rotisserie-like" mode to provide access to the facility surface for installation, removal, and other operations involving experiments or facility systems. During transportation the LDEF is supported by its four trunnions and keel pin on the LATS in the same manner as it is supported in the Shuttle. Figure 20 shows the LDEF on the LATS after experiment deintegration. Figure 21 is a photograph of the LATS with cover installed. This was the configuration used to transport LDEF when moved from LaRC to KSC and when moved between facilities at KSC.

Various dedicated electronic equipment was used for ground operations involving batteries, EPDS, and EIS.

Special scaffolding was used in experiment integration and later deintegration in SAEF II at KSC. Tray lifting fixtures were utilized in installing/removing experiment trays from LDEF. Tray rotators were used as support systems for experiment operations and also for moving experiment trays while in SAEF II. Experiment shipping containers were designed to provide a protective environment while being shipped from experimenters' facilities to/from KSC and

LaRC. Some of these facilities are shown in photographs (figs. 22 and 23) of operations in SAEF II.

LDEF EXPERIMENTS

Table I lists the LDEF experiment complement. Figure 24 shows the location of each experiment on LDEF. These experiments addressed the fields of basic science, technology, and applications problems. They generally measured specific space environments such as meteoroids, man-made debris, and radiation levels, or, they measured the effects of the space environments on typical spacecraft hardware. A few experiments measured space environmental effects on simple forms of life (seeds, spores, and eggs) and one experiment investigated the growth of crystals in reduced gravity.

Since the LDEF and experiment hardware had remained in space for almost 6 years, it was recognized that valuable knowledge of space environmental effects could be gained from detailed examinations of each piece of retrieved hardware--not just the 10,000 test specimens that were originally planned for study by the experiment principal investigators (P.I.'s). To facilitate these expanded investigations four Special Investigation Groups (SIG's) were established: Ionizing Radiation, Materials, Meteoroid and Debris, and Systems. In addition to investigating the retrieved non-test specimen hardware, these SIG's were also chartered to generate combined data bases which will contain the data they generate and the data the experiment P.I.'s in their respective disciplines generate. These combined data bases should simplify future access to the LDEF-derived information.

There are several hundred investigators from universities, industries, and government laboratories in the United States and nine foreign countries involved with the 57 LDEF experiments. Several hundred other investigators are involved with the LDEF SIG's. Approximately 3,500,000 students around the world are also involved in the investigations of the 13,000,000 tomato seeds which flew on the LDEF.

LDEF INTEGRATION AND LAUNCH

Some LDEF experiments were integrated into trays at LaRC while others were integrated at experimenters' facilities. Each fully loaded tray was vibration tested to certify safety for flight as required by the NASA STS.

Fully loaded trays were shipped from LaRC and experimenter facilities to the KSC for integration with the LDEF. Each experiment tray was inspected, photographed, and installed on the facility and the EIS checked. The loaded LDEF was weighed and the center of gravity measured and adjusted to be within preestablished limits by adding lead ballast to the end frames of the facility structure.

The LATS was transported to the Operations and Checkout (O & C) Building, the LATS cover removed and the LDEF removed and installed in the payload transport canister. At this point all operations with LDEF were "on line" and controlled by KSC. The LDEF and other payload components were installed in the Shuttle cargo bay at the launch pad.

The STS 41-C flight was launched on April 6, 1984. Figure 25 is a photograph of the liftoff. On April 7 the RMS was used to activate the EIS and then to deploy the LDEF in a gravity gradient stabilized attitude. The LDEF was deployed in a near-circular orbit at an altitude of 257 nautical miles. Figure 26 is a photograph of the LDEF immediately after release.

RETRIEVAL AND DEINTEGRATION

Background

When LDEF was launched in April 1984 the retrieval of LDEF was scheduled for March 19, 1985, on STS 51-D. In early February shortly before the scheduled retrieval the manifest was changed to accommodate a different payload and the LDEF retrieval was delayed indefinitely. In January 1986 the Challenger accident resulted in all Shuttle flights being temporarily halted.

When it became apparent that the LDEF retrieval would be delayed, possibly by years, orbit lifetime studies were initiated at LaRC and JSC to better plan the retrieval. In August 1986 LaRC studies indicated that LDEF reentry could occur between fall 1990 and spring/summer 1991. A large uncertainty was the solar flux expected from solar cycle 22. The first post-Challenger manifest published in March 1988 showed LDEF retrieval on STS-32 in July 1989 and later that year the August 1988 manifest showed the STS-32 launch in November 1989.

In early 1988 it was becoming apparent that solar cycle 22 was more severe than normal and was resulting in decreased orbital lifetime expectancy. Lifetime predictions continued to be updated and the lifetime margin beyond expected retrieval reviewed. Concern was mounting in 1989 that any significant delay in launch of the retrieval mission would result in the loss of LDEF. In June 1989 the launch date was set for December while LDEF reentry was predicted to be late January 1990. In December problems with refurbished launch pad 39A caused the scheduled December 18 launch to be delayed. Due to the problems associated with conducting a mission over the coming holidays and some apparent relief in the orbit lifetime, the mission was rescheduled for January 8, 1990. The launch on January 8 was delayed due to weather conditions. The STS-32 LDEF retrieval mission lifted off on January 9 and LDEF was retrieved on January 12. This was some 58 months later than originally planned in 1984. At the time of retrieval it was estimated that reentry would have occurred in approximately 8 weeks. Very little margin remained.

Operational Planning

To prepare for the retrieval mission, all plans and procedures covering LDEF deintegration operations at KSC were reviewed, updated, and approved. Detailed procedures included each step involved in the deintegration of each experiment tray and the handling and operations involved with all LDEF flight hardware. Additionally, plans were made for controlling and recording environmental conditions inside the orbiter bay from the time of landing rollout at Edwards until in the OPF at KSC, and also in each KSC facility involved in subsequent LDEF operations. The length of the LDEF mission made the data from the LDEF and its experiments very sensitive and special precautions to preserve the integrity of these data became paramount in all operational planning.

In the years between deployment and retrieval all LDEF ground support equipment (GSE), with the exception of the LATS, had been returned to LaRC for storage. In the 88/89 time period, all GSE was removed from storage, inventoried, refurbished, recertified, recalibrated and shipped to KSC in preparation for deintegration operations. The LATS was removed from storage at KSC, inspected, refurbished, and made ready for use.

All GSE to be used by experimenters, SIG's, and other support groups was shipped to KSC, properly documented, cleaned, and placed in the SAEF II building where LDEF off-line deintegration operations were to occur.

Retrieval Mission

The LDEF retrieval mission (STS-32) major cargo elements consisted of a SYNCOM IV-5 deploy, the LDEF retrieval, and the IMAX camera as a mid-deck experiment. Additionally the interim operational contamination monitor (IOCM) instrument was carried in the cargo bay and served to provide quantitative data on the contamination environment experienced by the LDEF during the retrieval and reentry phases of the mission. Constraints were placed on the rendezvous operations, proximity operations, operations after capture, and return of the LDEF to KSC so the retrieved LDEF would be in the same condition it was in space at the end of the 69 months of free flight. These constraints were considered in the planning and execution of waste water dumps and propulsion/control systems burns.

The retrieval flight was launched from KSC on January 9, 1990, into a 190 x 161 nmi orbit at an inclination of 28.5°. The SYNCOM was deployed on flight day 2. The orbit phasing maneuvers then began to rendezvous with the LDEF which was in a 179 nmi circular orbit. Rendezvous occurred on January 12. The proximity operations for LDEF capture are depicted in figure 27.

The capture maneuver planned was for the orbiter to pass 300 feet (was 590 feet actual) in front of LDEF's flight path, around to an inverted position approximately 300 feet (was 230 feet actual) above LDEF and to descend along the R BAR (radius vector axis) for capture. This R BAR approach minimized reaction control system (RCS) firing contamination of LDEF. The LDEF was captured, using the grapple fixture in tray C1, at 9:16 a.m. CST on orbit 50 east of Brazil. After capture and until payload bay door closing, the attitude of the Shuttle was maintained so the LDEF was always positioned in the wake of the orbiter body. This was done so as not to compromise the effects on LDEF surfaces of the atomic oxygen encountered during the 69 months of free flight.

After capture a detailed photographic survey and visual inspection of the LDEF was made. The purpose of the photo survey was to document the condition of each experiment prior to undergoing the rigors of reentry, landing, and the ferry flight back to KSC. The RMS was used to orient the LDEF so that photographs of each experiment tray and of the overall spacecraft could systematically be taken. The survey photographs were made using KODAK 5017 (Ektachrome 64) film. Original negatives of this survey are archived at JSC.

After completion of the photo survey the LDEF was berthed and the keel latched on orbit 54 at 2:40 p.m. CST over the Indian Ocean. The attitude of the Shuttle was controlled prior to the payload bay door closings at the end of the 11-day mission to thermally condition the LDEF so experiment temperatures during reentry and landing would not exceed on-orbit temperatures. After landing and roll-out at Edwards on January 20, shuttle payload bay ground purge was established to maintain the desired payload bay environment. During the 69 months in orbit the LDEF had completed 32,422 orbits of the Earth and travelled over 741,928,000 nmi.

Prior to being mated to the 747 ferry aircraft, special instrumentation was placed in the orbiter cargo bay to monitor and record environmental conditions during the ferry flight. A limited photo survey was also made of the end of LDEF facing the cargo bay hatch door.

The ferry flight which included three 747 refueling stops and an overnight stay, was completed on January 26. A photograph of the orbiter/747 aircraft just prior to touchdown at KSC is shown in figure 28. The orbiter/747 was moved to the mate/demate facility and the operation to remove the orbiter began. A photograph, figure 29, taken at the facility shows the cargo bay purge hookup. Cargo bay purge was also used at intermediate stops on the ferry flight and during the tow from the mate/demate facility to the OPF. The transfer to the OPF on January 27 started the "on-line" processing.

Shuttle-LDEF Deintegration

Inside the OPF orbiter operations were completed and the cargo bay doors opened under clean room conditions. Figure 30 is a photograph of this operation. After the doors were opened a special team made a radiation survey of the LDEF to ensure personnel safety. The removal of the LDEF from the orbiter and placement in the KSC payload transport canister is shown in figures 31 and 32. During the lift of LDEF from the orbiter a photo survey was made of all visible experiment trays. The payload canister doors were closed and made ready to leave the OPF.

The payload transport canister was moved from OPF to the O&C building. During the move, ground purge was used to control the environment inside the payload canister. Inside the O&C the LDEF was lifted from the canister and placed in the LATS. This ended "on-line" operations under control of KSC operations and began off-line operations under control of LaRC. The LATS had been cleaned to clean room conditions. A photograph of this transfer is shown in figure 33. After LDEF was placed on the LATS, the LATS cover was installed and the LATS, with a towed unit providing electrical power for the air conditioning, was moved to the SAEF II building to begin the months of LDEF deintegration.

LDEF/Experiment Deintegration

The LATS was placed in the airlock of SAEF II and its exterior cleaned. It was then moved from the airlock into SAEF II clean room. These operations are shown in figures 34 and 35. The clean room was maintained at Class 100,000 throughout the ensuing deintegration. The movement of all personnel and equipment into and out of the clean room was tightly controlled. All equipment was thoroughly cleaned before entering the clean room and all personnel wore appropriate clean room clothing. A major objective was to minimize contamination of the LDEF and experiments while in the clean room.

The LATS cover was removed and the supporting structure on the LATS was configured for the rotation mode. Figures 36 and 37 show typical operations. The LDEF was then ready for "first-look" visual inspection by the press, investigators, SIG members, and other appropriate personnel (see fig. 38).

A detailed photo survey of the LDEF and each experiment was made in parallel with the inspection. The survey was done using KODAK Vericolor III 160 film and using film identical (same lot and emulsion) as that used for the in-orbit photo survey. Strobe lighting was used. The original negatives for this survey are archived at KSC.

Radiation measurements were made by the Radiation SIG with LDEF in various rotation positions. The instrumentation was set up each evening and left overnight to collect data. The instrumentation setup is shown in figure 39.

After inspections, photo survey and radiation measurements were completed, scaffolding was rolled into place along the side and ends of LDEF to provide access for deintegration. The Meteoroid and Debris (M&D) Team made a visual survey and recorded the presence of significant meteoroid impacts on all tray clips, clip bolts, and tray flanges that would be affected by the placement of experiment covers. Protective covers were then placed on all experiment trays to protect experiment surfaces during tray removal. Tray covers were also used in other operations in SAEF II and when trays were shipped.

The deintegration of trays from the facility started on February 23 and was completed on March 27. The sequence of tray removal is shown in Table II. The correlation of tray number and experiment number is shown in Table I and figure 24.

Figure 40 shows a tray lifting fixture being bolted to a tray flange. After the tray lifting fixture was secured the clips holding the tray in place were removed. The torque required to break each clip bolt free was recorded. Figure 41 shows a typical tray after being removed and lowered to the floor being inspected for space debris impacts on tray flanges. These surfaces would later be in contact with tray rotator fixtures and any craters present could be affected.

Outside surfaces of each tray were inspected for contamination and discoloration and photographed if present while still being suspended from the overhead crane. A typical photograph is shown in figure 42. Each tray was then moved to the M&D work station where the complete surface of the experiment and tray was inspected for impact craters, and documented using special instrumentation. Figure 43 shows a tray being scanned.

Each tray was then taken to a special area for a detailed photo survey. Figure 44 shows such a typical photo setup. The front and back surface of each experiment tray was photographed in detail. Closeups of each 1/6 of the front and the back of peripheral trays and 1/4 of the front and the back of end trays were made. Additional closeups were made of any unusual details found. All photographs were processed by the KSC and all original negatives are archived there. Photographs were taken using KODAK Vericolor III 160 film using color balanced flood lights.

Experiments were checked for contamination by Systems SIG members. Measurements were made and recorded when appropriate. Figure 45 shows a typical tray setup for contamination measurements.

After M&D scan, photo survey, and contamination measurements were complete, trays were ready for deintegraton if appropriate. Experiments were removed from those trays with multiple experiments. Batteries were checked for leaks and voltages measured and then removed. MTM tape recorders were removed from each EPDS and returned to the manufacturer for checkout before data readout.

Thermal properties were measured on some tray and experiment surfaces. Figure 46 shows such measurements being made.

Each experimenter performed his unique procedures as required. This included additional photos, sample removal, measurements and examinations. Support was provided as required.

The final operation for trays and experiments was the preparation and shipping to the experimenters' laboratories. Figure 47 shows a tray being placed in a shipping container.

After the tray deintegration was complete, thermal panels and other systems were removed. The wiring harness was inspected, tested, and removed. The lead ballast used to adjust the LDEF c.g. when flown was removed. The EIS was removed and tested. Photo and video surveys were made of the LDEF structure. Each surface, both interior and exterior, was included. The M&D Team made a systematic scan of the outer surfaces of the facility structure using the same instrumentation as used in individual tray surveys. Contamination measurements, tape lifts and scrapings were made of SIG-specified areas of structure contamination.

Nondestructive tests (eddy current) were made of LDEF welds and dye penetrant tests were made on trunnion and keel pin mounting holes in the facility center ring (see fig. 48) and the trunnion mounting holes in the end support beam. Torque measurements were made on selected bolted joints of the facility structure. The flight trunnions and the keel pin were removed for testing and replaced with those used during ground transport.

After completion of LDEF deintegration and testing, the bare facility structure was then made ready for storage. The LATS cover was installed and the LATS removed from the SAEF II building (see fig. 49). The LATS was transported (see fig. 50) to a hangar for storage on May 14, 1990. At present the facility remains in storage, its future uncertain.

REFERENCES

1. LDEF 840-2: Long Duration Exposure Facility (LDEF) Experiment Users Handbook, Prepared by Staff, LDEF Project Office. January 15, 1978.

2. Greene, Robert F., Jr.: Thermal Design and Experiment Thermal Integration of the Long Duration Exposure Facility. 3rd AIAA/ASME Joint Thermophysics, Fluids Plasma and Heat Transfer Conference, St. Louis, MO., June 1982, AIAA paper No. 82-0829.

3. Berrios, William M.; and Greene, Robert F., Jr.: Long Duration Exposure Facility (LDEF) - Thermal Model Description. LDEF No. 840-008C, June 1983 revision.

4. JSC 19016. Cargo Systems Manual - LDEF Retrieval. STS 51-D. Prepared by Mariann Albjerg, NASA-JSC. Final, Revision A, January 4, 1985.

5. JSC-22959-32. National Space Transportation System Flight Data File: Rendezvous, STS-32 - Long Duration Exposure Facility (LDEF), November 22, 1989.

6. JSC-23156-32. National Space Transportation System Flight Data File: Flight Plan, STS-32 (Cycle 2R Trajectory), November 22, 1989.

7. Long Duration Exposure Facility Guide to Location of LDEF Experiments and Systems: Prepared by Glenna D. Martin, LDEF Project Office, December 15,1989.

Table 1.- LDEF experiment complement

EXP. NO.	TITLE	TRAY NOS.
A0015	Free-Flyer Biostack Experiment Institute fur Flugmedizin, DFVLR	C2, G2
A0019	Influence of Extended Exposure in Space on Mechanical Properties of High-Toughness Graphite-Epoxy Composite Material University of Michigan	D12
A0023	Multiple Foil Microabrasion Package University of Kent	C3, C9, D12, E6, H11
A0034	Atomic Oxygen Stimulated Outgassing Southern University/NASA-MSFC	C3, C9
A0038	Interstellar Gas Experiment NASA-JSC/University of Bern	E12, F6, H6, H9
A0044	Holographic Data Storage Crystals for LDEF Georgia Institute of Technology	E5
A0054	Space Plasma High Voltage Drainage TRW Space and Technology Group	B4, D10
A0056	Exposure to Space Radiation of High-Performance Infrared Multilayer Filters and Materials Technology Experiments University of Reading/British Aerospace	B8, G12
A0076	Cascade Variable Conductance Heat Pipe McDonnell Douglas Astronautics Company	F9
A0114	Interaction of Atomic Oxygen with Solid Surfaces at Orbital Altitudes University of Alabama in Huntsville/NASA-MSFC	C3, C9
A0133	Effect of Space Environment on Space Based Radar Phased Array Antenna Grumman Aerospace Corporation	H7
A0134	Space Exposure of Composite Materials for Large Space Structures NASA-LaRC	B9

Table 1.- (continued)

EXP. NO.	TITLE	TRAY NOS.
A0135	Effect of Space Exposure on Pyroelectric Infrared Detectors NASA-LaRC	E5
A0138-1	Study of Meteoroid Impact Craters on Various Materials CERT/ONERA-DERTS	B3
A0138-2	Attempt at Dust Debris Collection with Stacked Detectors CERT/ONERA-DERTS	B3
A0138-3	Thin Metal Film and Multilayers Experiment CNRS/LPSP	B3
A0138-4	Vacuum Deposited Optical Coatings Experiment Optical Division, Matra S. A.	B3
A0138-5	Ruled and Holographic Gratings Experiment Inst. SA/JOBIN-YVON Division	B3
A0138-6	Thermal Control Coatings Experiment CERT/ONERA-DERTS, CNES/CST	B3
A0138-7	Optical Fibers and Components Experiment CERT/ONERA-DERTS	B3
A0138-8	Effect of Space Exposure of Some Epoxy Matrix Composites on Their Thermal Expansion and Mechanical Properties Space Division, Matra S. A.	B3
A0138-9	The Effect of the Space Environment on Composite Materials Aerospatiale	B3
A0138-10	Microwelding of Various Metallic Materials Under Ultravacuum Aerospatiale	B3
A0139A	Growth of Crystals from Solutions in Low Gravity Rockwell International Science Center Technical University of Denmark	G6

Table I.- (continued)

EXP. NO.	TITLE	TRAY NOS.
A0147	Passive Exposure of Earth Radiation Budget Experiment Components The Eppley Laboratory, Inc.	B8, G12
A0171	Solar Array Materials Passive LDEF Experiment NASA-MSFC/NASA-LeRC/NASA-GSFC Jet Propulsion Laboratory	A8
A0172	Effects of Solar Radiation on Glasses NASA-MSFC/Vanderbilt University	D2, G12
A0175	Evaluation of Long-Duration Exposure to the Natural Space Environment on Graphite-Polyimide and Graphite-Epoxy Mechanical Properties Rockwell International Corp. (Tulsa Facility)	A1, A7
A0178	A High Resolution Study of Ultra-Heavy Cosmic Ray Nuclei Dublin Inst. for Advanced Studies, ESA-ESTEC	A2, A4, A10, B5, B7, C5, C6, C8, C11, D1, D5, D7, D11, E2, E10, F4
A0180	The Effect of Space Environment Exposure on the Properties of Polymer Matrix Composite Materials University of Toronto	D12
A0187-1	Chemistry of Micrometeoroids NASA-JSC/Univ. of Washington, Rockwell Int. Science Center	A3, A11
A0187-2	Chemical and Isotopic Measurements of Micrometeoroids by Secondary Ion Mass Spectrometry McDonnell Center for the Space Sciences Max-Planck Institute fur Nuclear Physics Munich Technical University Ernst-Mach Institute Dornier System Manufacturing Company	C2, E3, E8
A0189	Study of Factors Determining the Radiation Sensitivity of Quartz Crystal Oscillators Martin Marietta Laboratories	D2
A0201	Interplanetary Dust Experiment Institute for Space Science and Technology NASA-LaRC North Carolina State University	B12, C3, C9, D6, G10, H11

Table 1.- (continued)

EXP. NO.	TITLE	TRAY NOS.
M0001	Heavy Ions in Space Naval Research Laboratory	H3, H12
M0002-1	Trapped Proton Energy Spectrum Determination AF Geophysics Laboratory	D3, D9, G12
M0002-2	Measurement of Heavy Cosmic-Ray Nuclei on LDEF University of Kiel, Federal Republic of Germany	E6
M0003	Space Environment Effects on Spacecraft Materials The Aerospace Corporation	D3, D4, D8, D9
M0004	Space Environment Effects on Fiber Optics Systems AF Weapons Laboratory	F8
M0006	Space Environment Effects AF Technical Applications Center	C2
P0003	LDEF Thermal Measurements System NASA-LaRC	Center ring
P0004-1	Seeds in Space Experiment George W. Park Seed Company, Inc.	F2
P0004-2	Space-Exposed Experiment Developed for Students (SEEDS) NASA Headquarters	F2
P0005	Space Aging of Solid Rocket Materials Morton-Thiokol, Inc.	Center ring
P0006	Linear Energy Transfer Spectrum Measurement Experiment University of San Francisco/NASA-MSFC	F2
S0001	Space Debris Impact Experiment NASA-LaRC	A5, A6, A12, B1, B2, B6, B8, B11, C4, C7, D2, D6, E1, E4, E7, E11, F1, F3, F5, F7, F10, F11, G4, G8, H5

Table 1.- (concluded)

EXP. NO.	TITLE	TRAY NOS.
S0010	Exposure of Spacecraft Coatings NASA-LaRC	B9
S0014	Advanced Photovoltaic Experiment NASA-LeRC	E9
S0050	Investigation of the Effects of Long Duration Exposure of Active Optical System Components Engr. Exp. Station, Georgia Inst. of Technology	E5
S0050-1	Investigation of the Effects of Long Duration Exposure on Active Optical Materials and UV Detectors NASA-LaRC	E5
S0069	Thermal Control Surfaces Experiment NASA-MSFC	A9
S0109	Fiber Optic Data Transmission Experiment Jet Propulsion Laboratory	C12
S1001	Low Temperature Heat Pipe NASA-GSFC/NASA-ARC	F12, H1
S1002	Investigation of Critical Surface Degradation Effects on Coatings and Solar Cells Developed in Germany Messerschmitt-Bolkow-Blohm Space Division	E3
S1003	Ion Beam Textured and Coated Surfaces Experiment NASA-LeRC	E6
S1005	Transverse Flat Plate Heat Pipe Experiment NASA-MSFC/Grumman Aerospace Corporation	B10
S1006	Balloon Materials Degradation Texas A&M University	E6

Table 2.- Sequence of tray removal.

LANGLEY RESEARCH CENTER

APPROVAL

ACCOMPLISHMENT

LDEF
ORDER OF TRAY REMOVAL

LEVEL

Pg 1 of 2

PLAN
3 / 28 / 90

MONTH	FEB						MARCH																		
DATE	23	26	27	28	1	2	5	6	7	8	9	12	13	14	15	16	19	20	21	22	23	26	27	28	29
Remove F-2, C-5, C-6	▼																								
Remove D-7, D-8, D-9		▼																							
Remove F-12 MTM, E-4			▼																						
Remove D-4, D-3, A-8, A-9				▼																					
Remove B-10, C-8, C-4, B-1					▼																				
Remove C-9, C-3, H-5, F-10, F11						▼																			
Remove F-6, E-12, H-9, H-6							▼																		
Remove B-3, B-2, E-1, F-5								▼																	
Remove A-11, A-6, G-6, F-7, B-11,									▼																
Remove B-12, A-5, A-4, A-3										▼															
Remove E-8, D-11, D-10, E-3											▼														
Remove E-9												▼													
Remove B-9, C-2, G-2, B-8													▼												
Remove F-8, H-7, E-6														▼											
Remove G-12, H-12, H-3, D-12															▼										
Remove D-2, H-11, G-10, D-6																▼									
Remove C-11, E-5, F-1, B-4																	▼								
Remove A-7, C-7, A-1																		▼							
Remove C-12, A-10, A-12, B-5, E-11																			▼						
Remove F-4, B-6, D-5, E-7, F-3																				▼					
Remove E-10, G-4, D-1, G-8																					▼				
Remove B-7, A-0139A Batteries																						▼			
Remove A-2, E-2, P-0003, H-1, F-12, P-0005, F-9																							▼		
Process Trays																									

Note: Refer to approved hardware deintegration schedule.

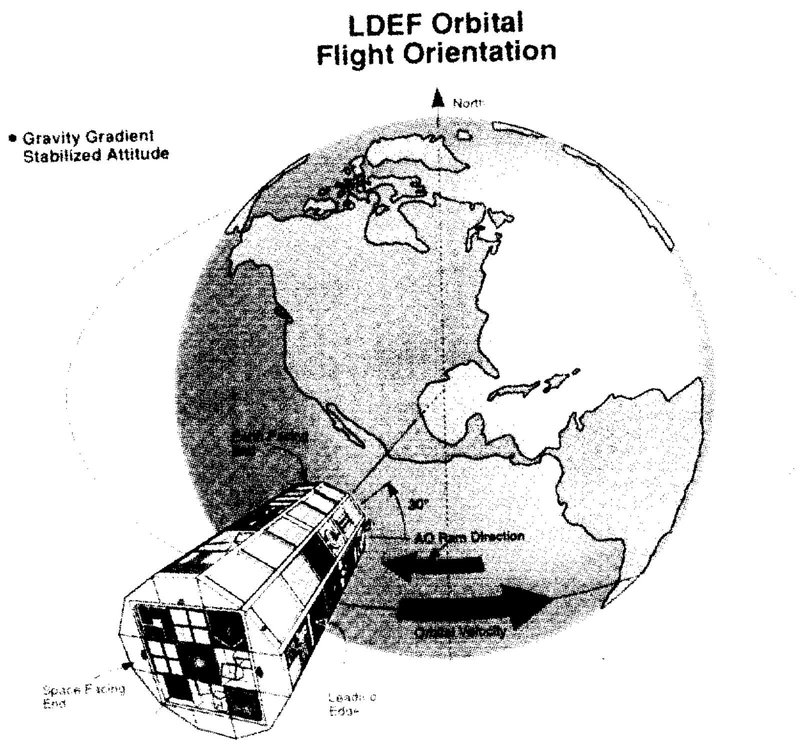

Figure 1.- LDEF orbital flight orientation. (Photo L-91-652)

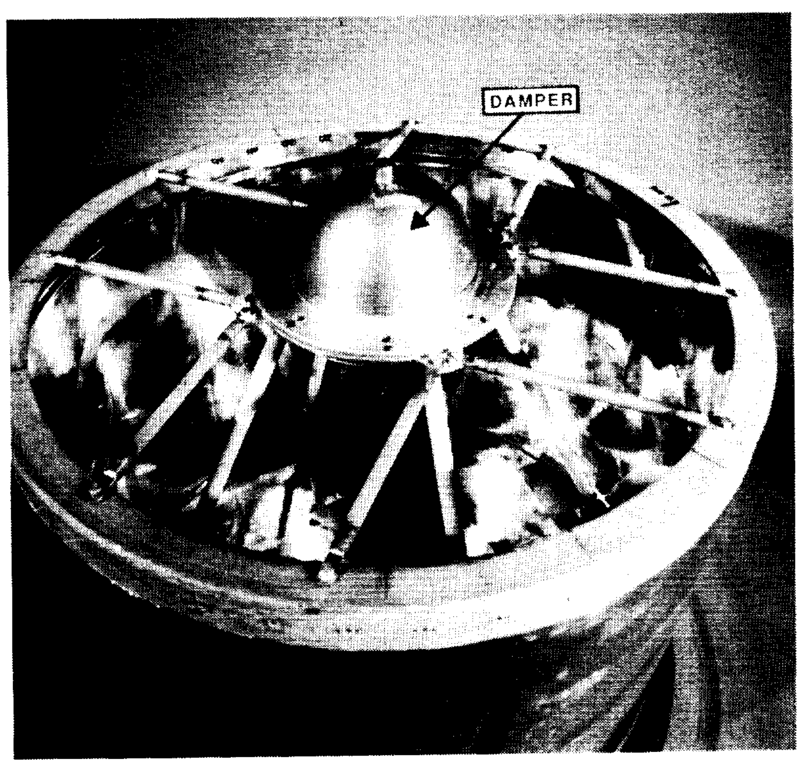

Figure 2.- Photograph of viscous magnetic rate damper and protective housing base.
(Photo KSC-390C-3383.07)

Figure 3.- Photograph of LDEF several minutes after deployment. (Photo L-84-04337)

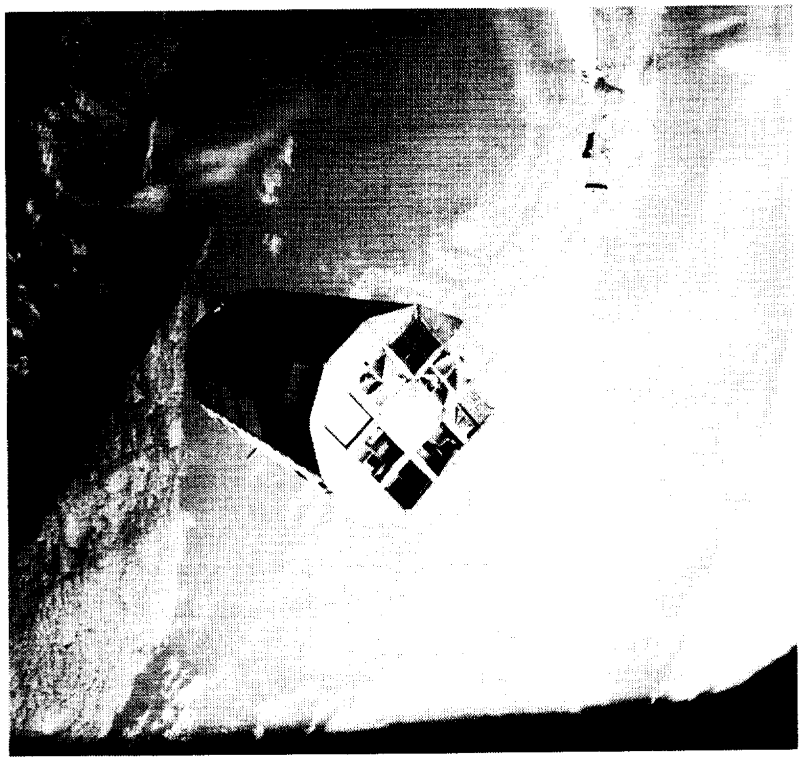

Figure 4.- Photograph of LDEF prior to retrieval. (Photo L-90-10468)

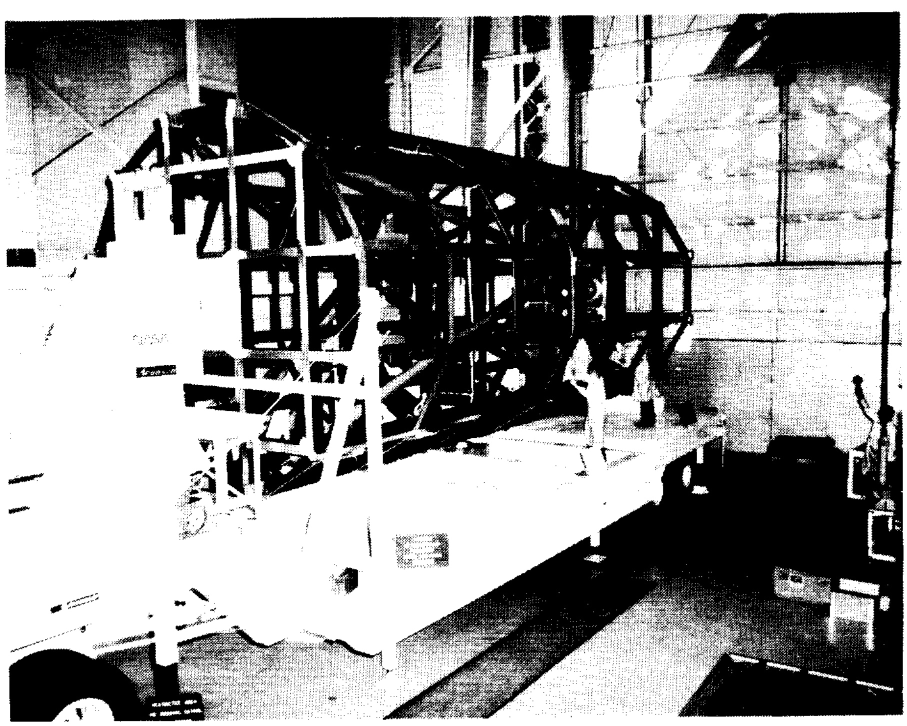

Figure 5.- LDEF structure mounted on LDEF Assembly and Transportation System (LATS). (Photo L-83-2797)

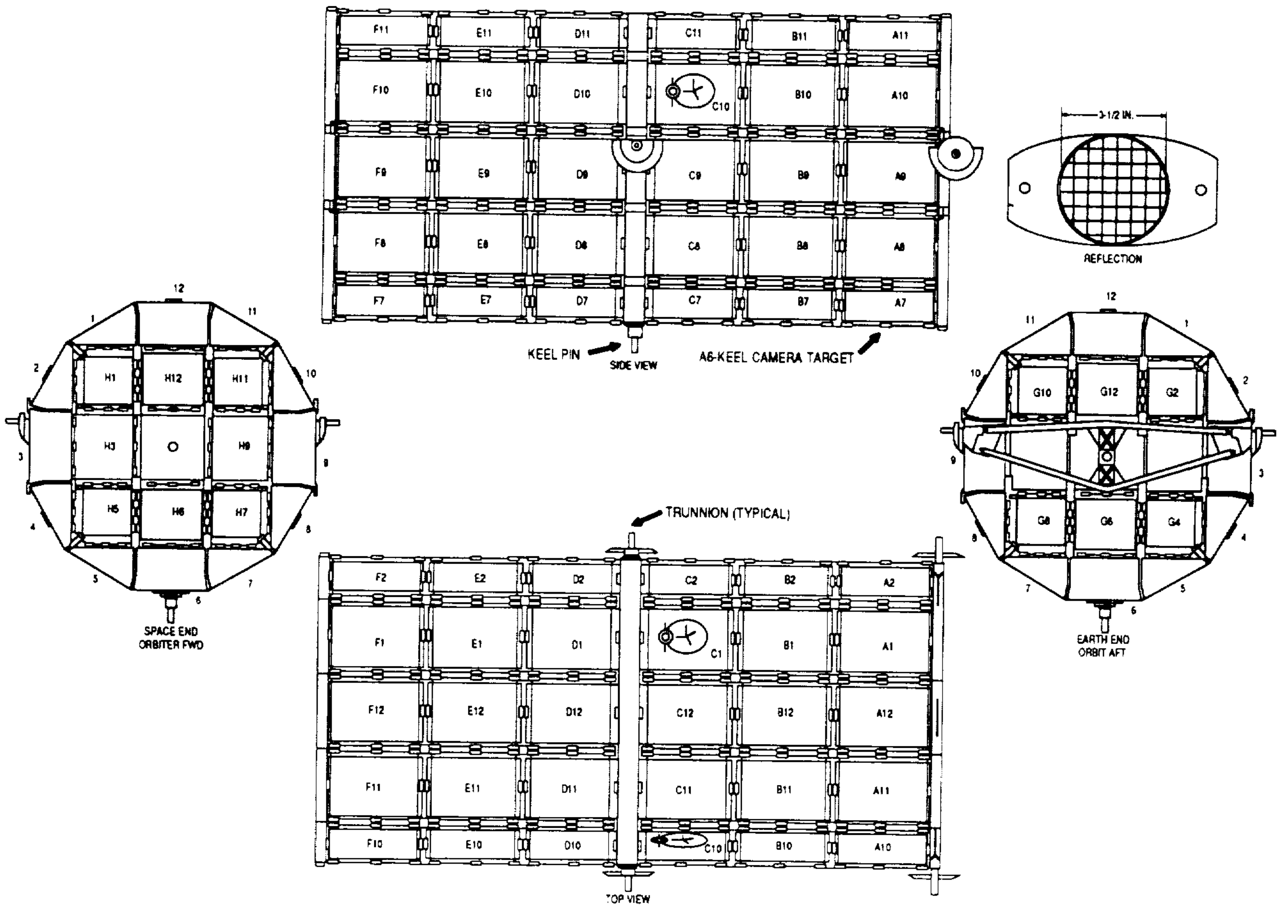

Figure 6.- LDEF structural configuration and identification of experiment locations.

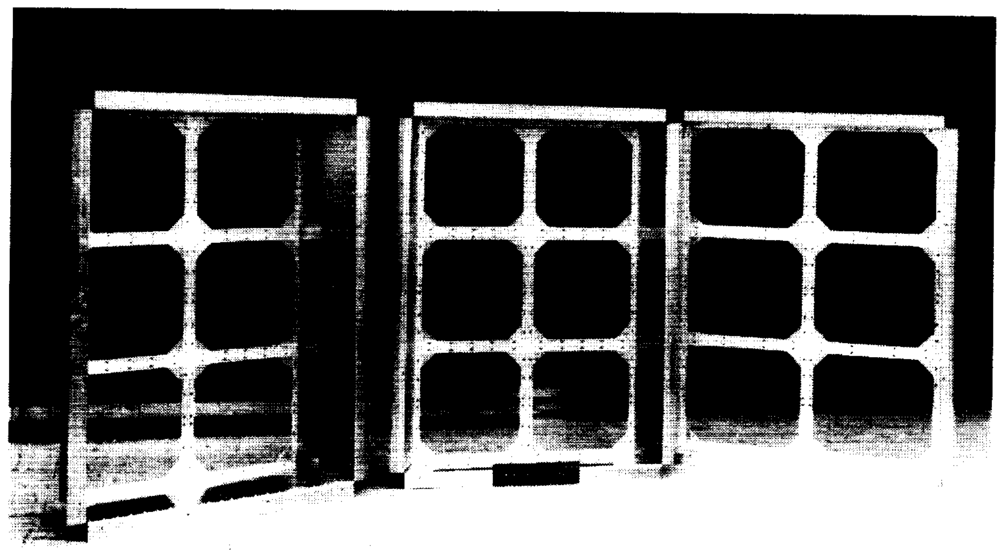

Figure 7.- Photograph of 12-inch deep, 6-inch deep, and 3-inch deep peripheral experiment trays.
(Photo L-76-3431)

TRAY MOUNTING TO LDEF STRUCTURE

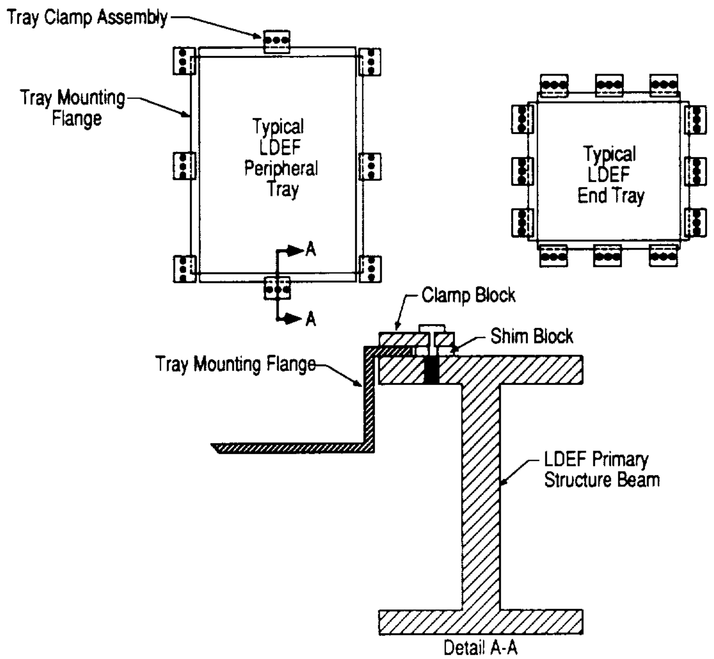

Figure 8.- Sketch of tray mounting to LDEF structure.

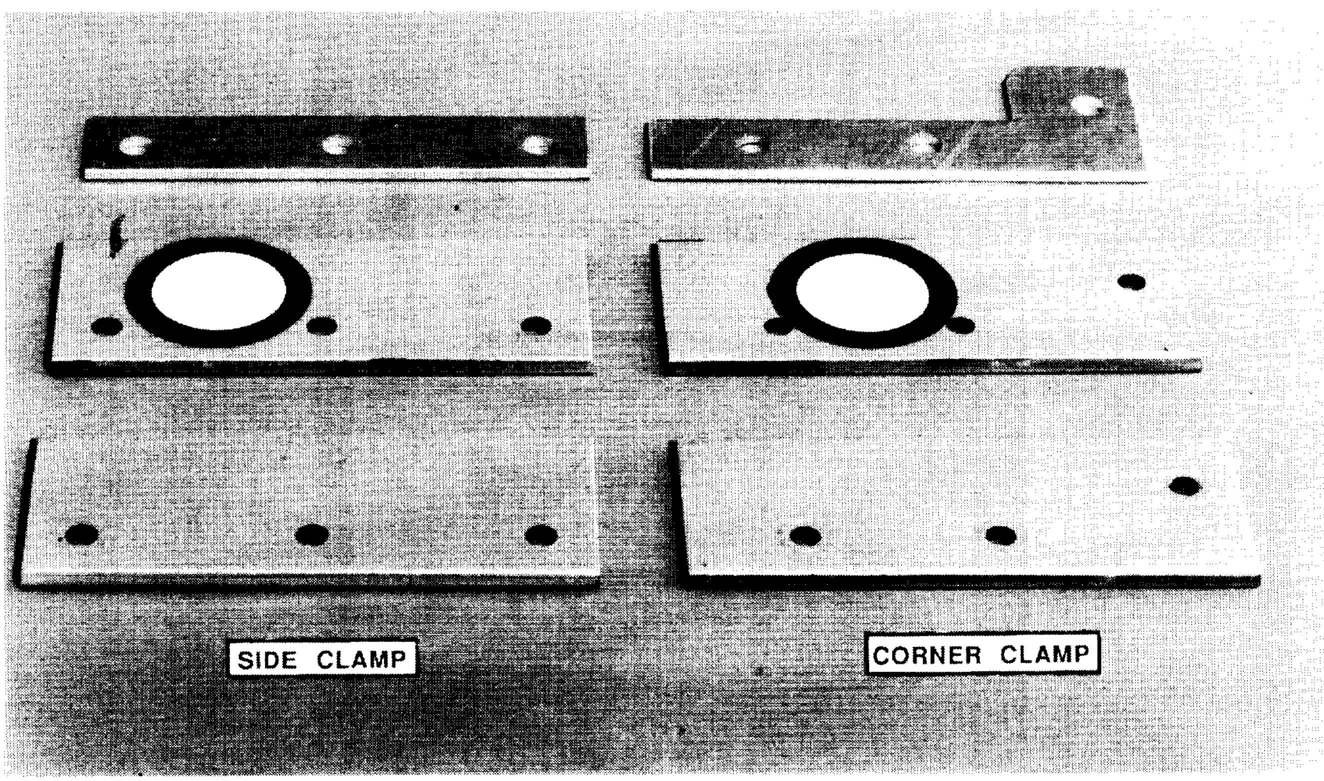

Figure 9.- Typical side and corner tray clamps. Clamps with and without white dots are shown. (Photo L-83-9460)

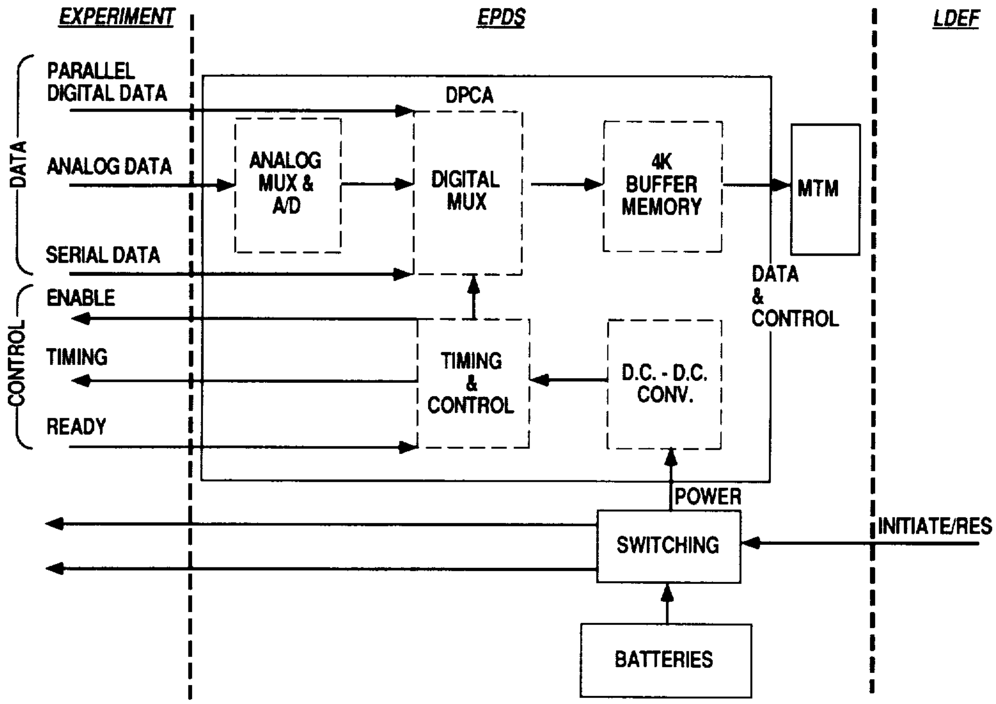

Figure 10.- Experiment power and data system (EPDS) block diagram.

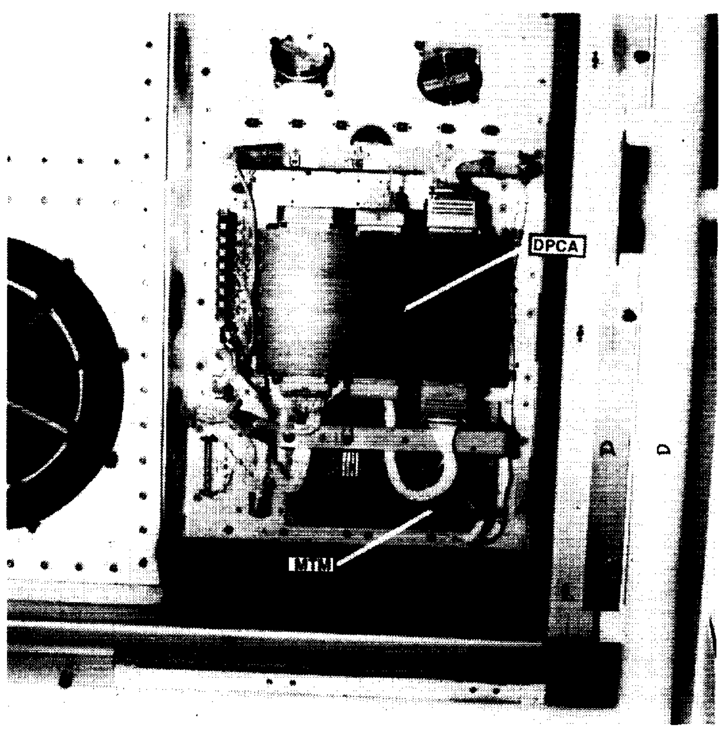

Figure 11.- Typical experiment power and data system (EPDS) installation in experiment tray. (Photo KSC-390C-2003.12)

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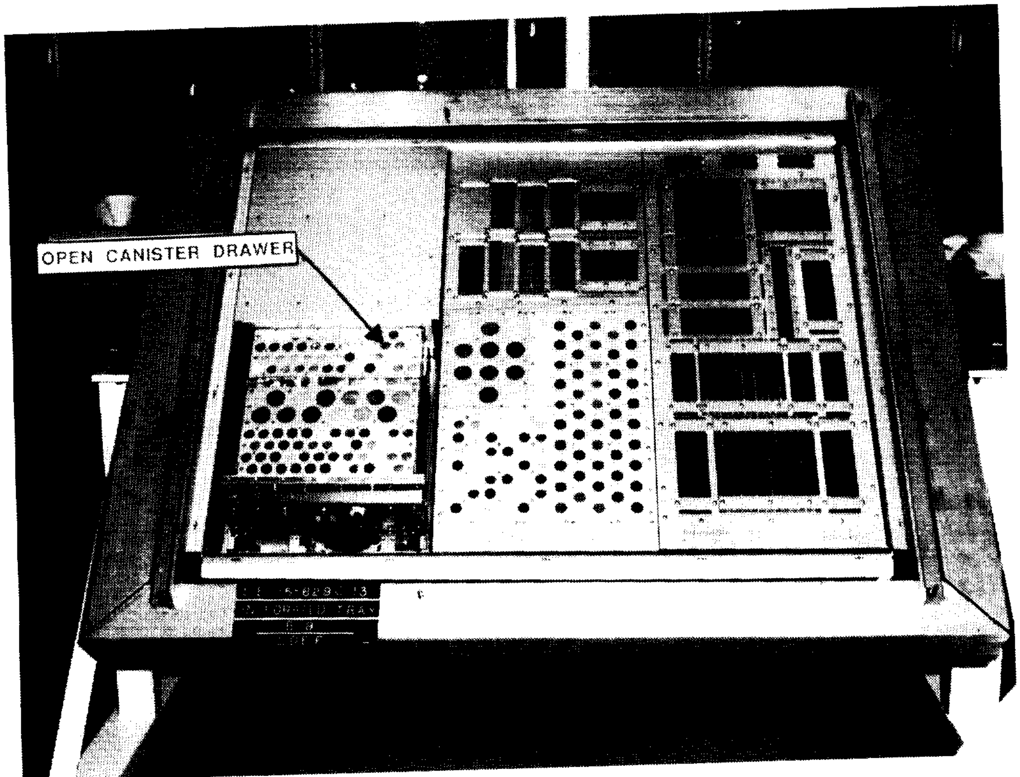


Figure 12.- Photograph of experiment environmental control canister (EECC) with test specimens installed. (Photo L-83-10,250)

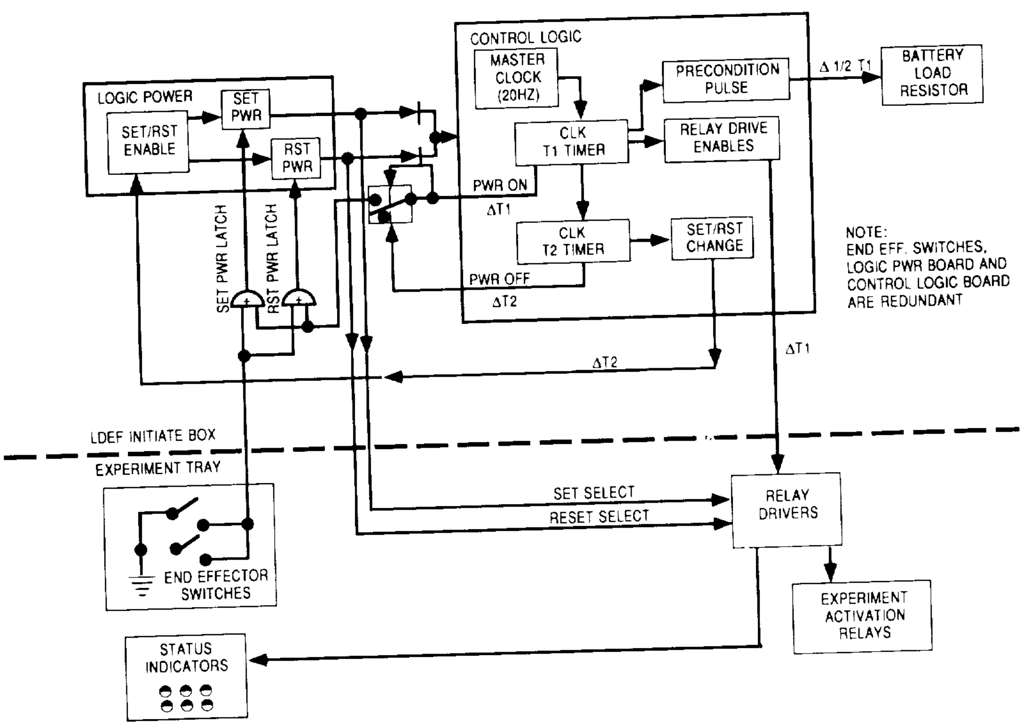


Figure 13.- Experiment initiate system (EIS) functional flow.

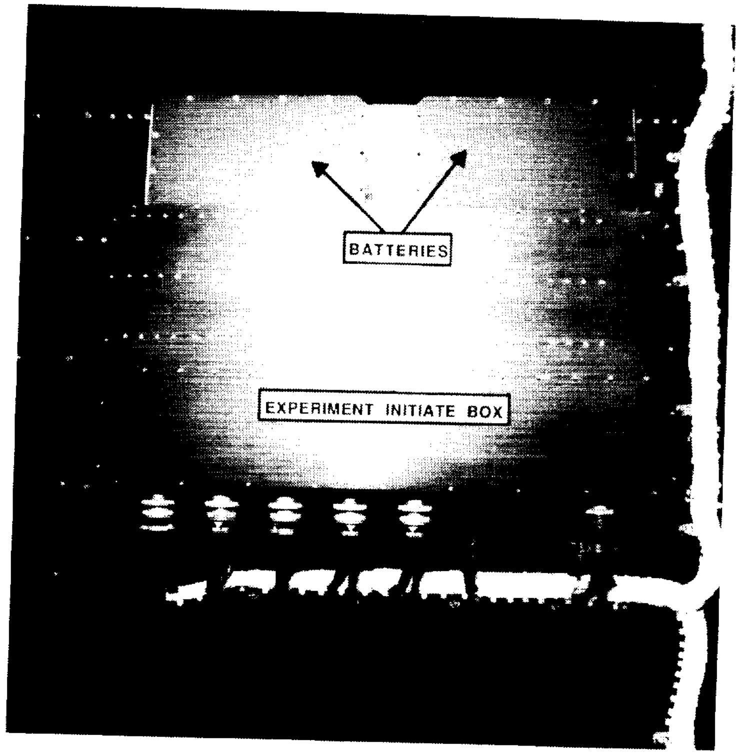
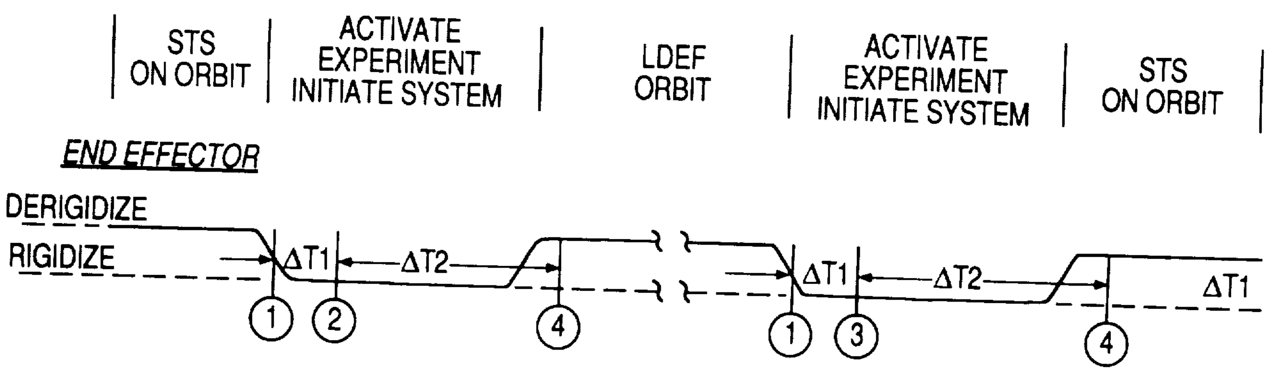


Figure 14.- Experiment initiate system (EIS) box and batteries mounted on center ring. (Photo KSC-390C-1461.02)



(1) Begin control cycle

(2) If reset and end effector stays in for ΔT1, then "set" - status indicators change from black to white

(3) If set and effector stays in for ΔT1, then "reset" - status indicators change from white to black

(4) Terminate control cycle

Figure 15.- Experiment initiate system (EIS) operational sequence.

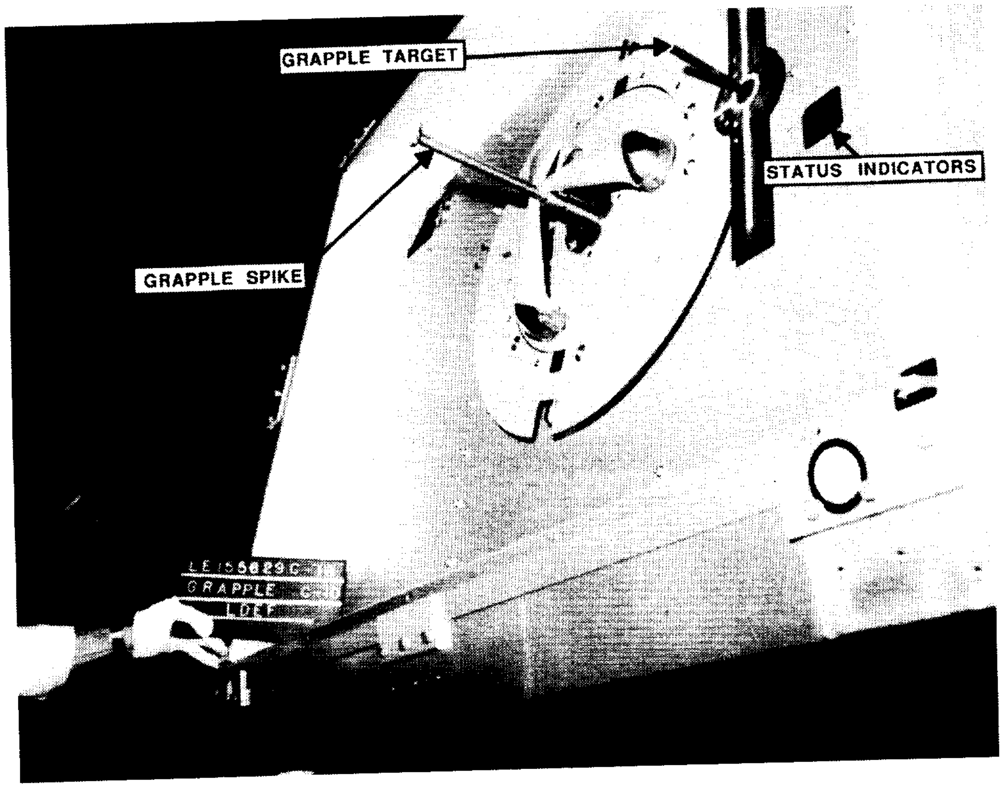


Figure 16.- Grapple fixture in tray C-10 (used to activate experiment initiate system [EIS]). (Photo L-84-7315)

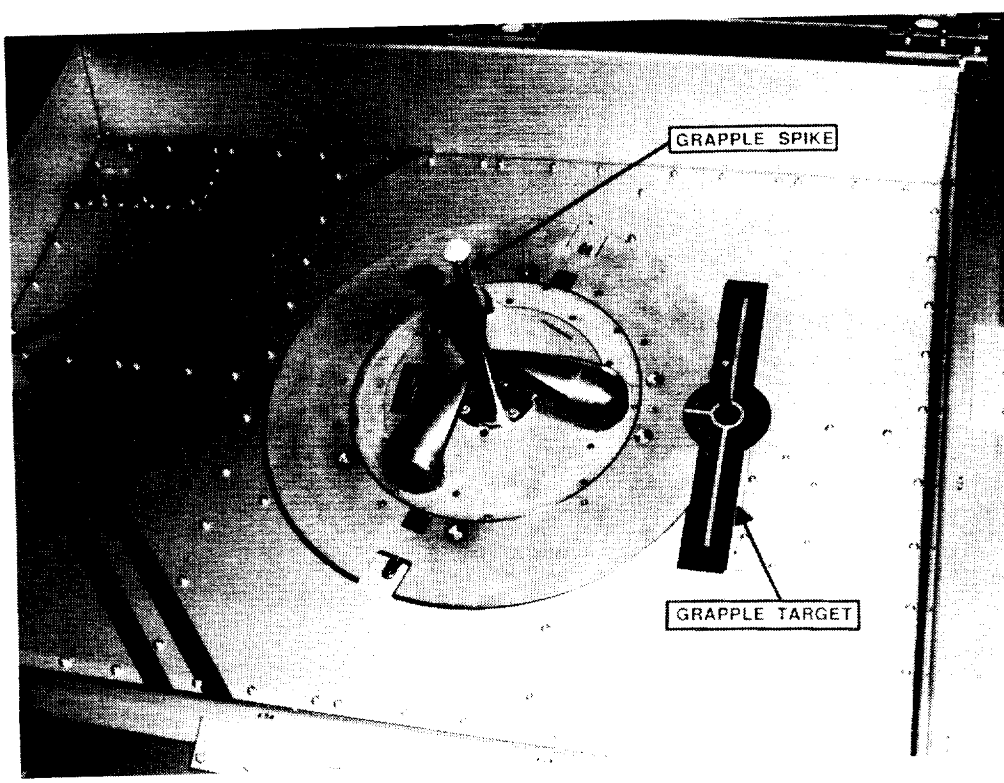


Figure 17.- Grapple fixture in tray C-1 (used for deployement and retrieval). (Photo L-90-01503)

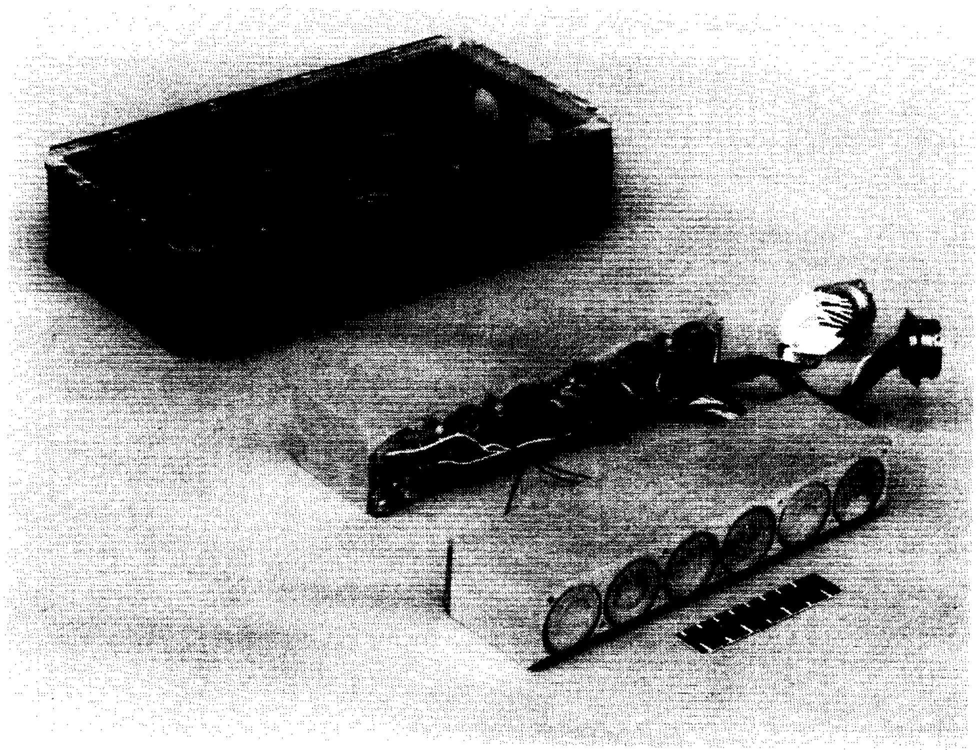


Figure 18(a).- Battery components. (Photo L-78-5152)

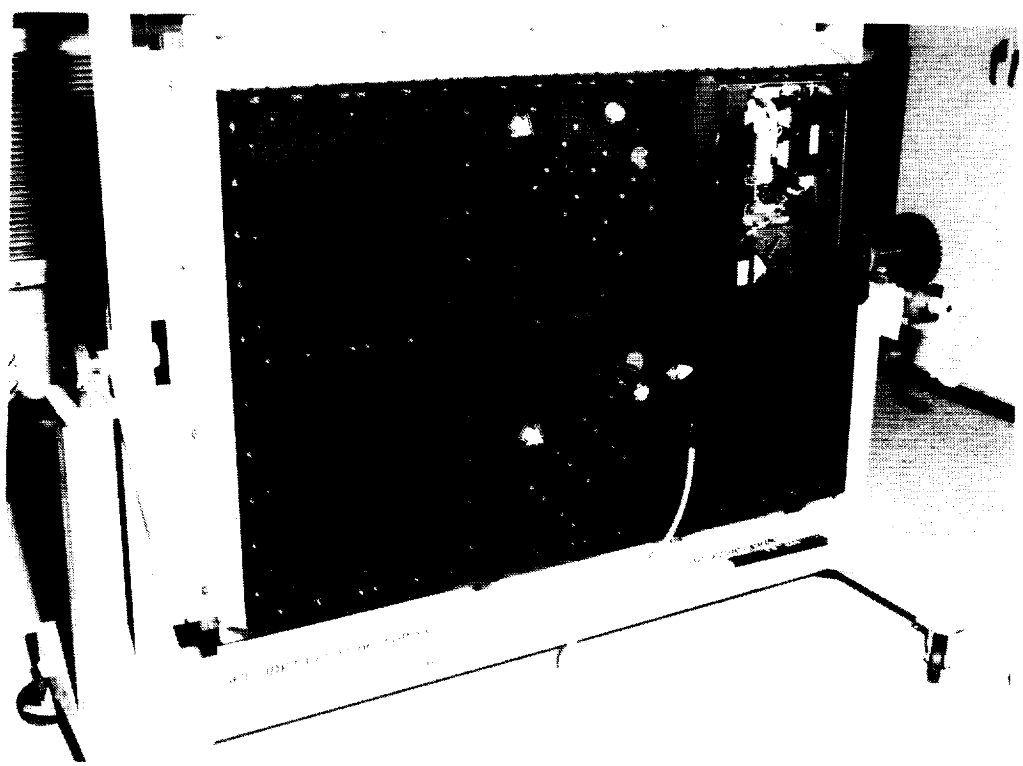


Figure 18(b).- Batteries located on back of typical experiment. (Photo L-90-03121)

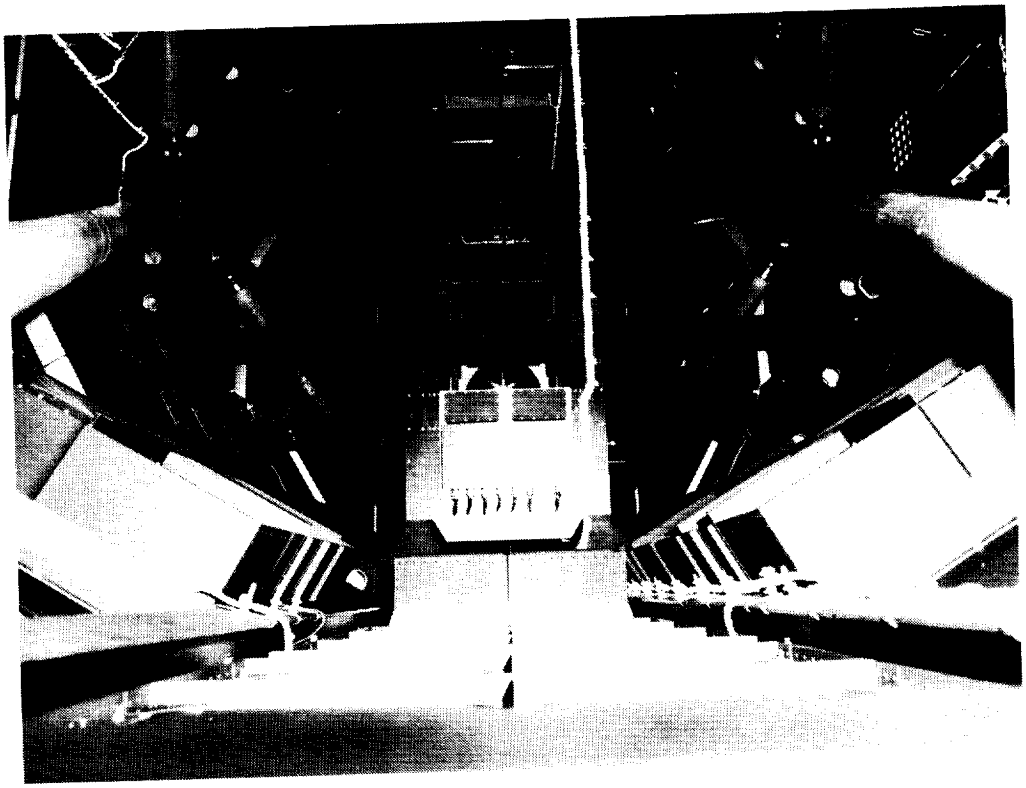


Figure 19.- Interior of LDEF. Note experiment initiate system (EIS) and batteries on center ring. (Photo L-90-01533)

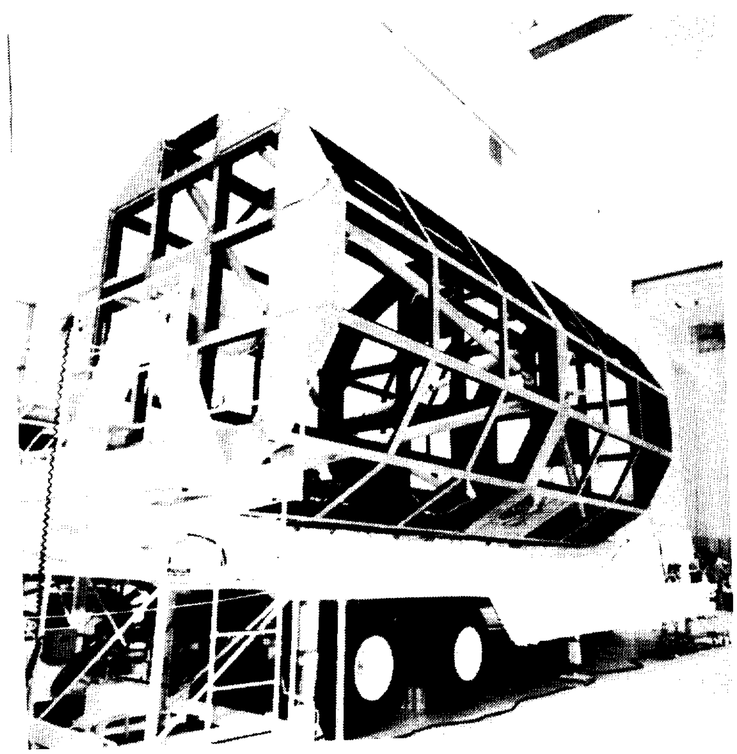


Figure 20.- LDEF on LDEF Assembly and Transportation System (LATS) after experiment tray removal. (Photo KSC-390C-2366.07)

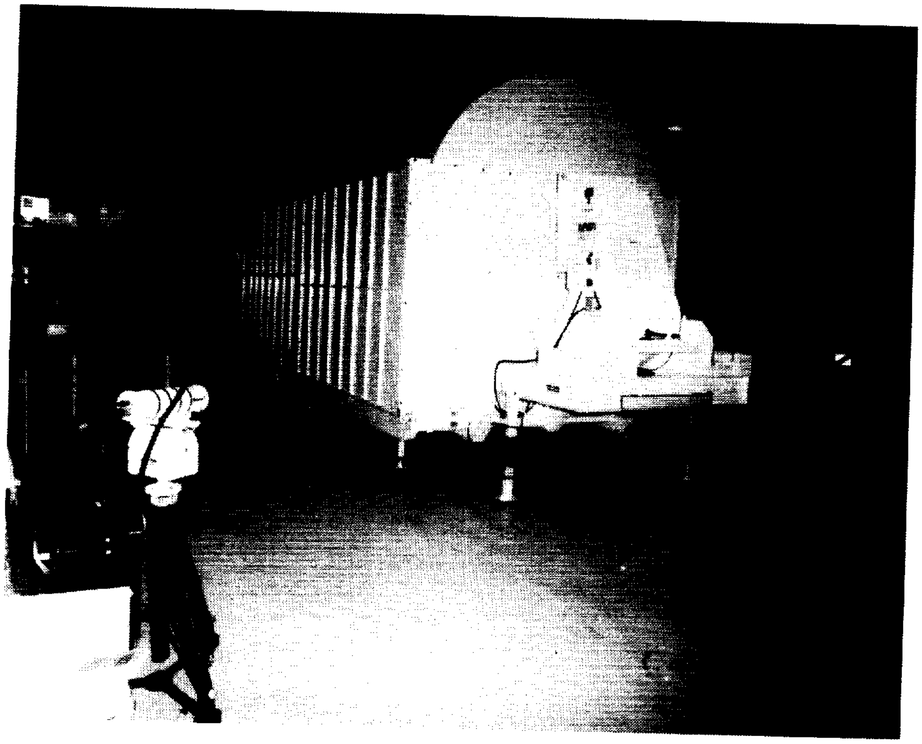


Figure 21.- LDEF Assembly and Transporation System with cover installed. (Photo KSC-390C-2774.02)

Figure 22.- Ground support equipment in use in Spacecraft Assembly and Encapsulation Facility II (SAEF II). (Photo KSC-390C-2749.08)

Figure 23.- Typical tray shipping container. (Photo KSC-390C-1471.12)

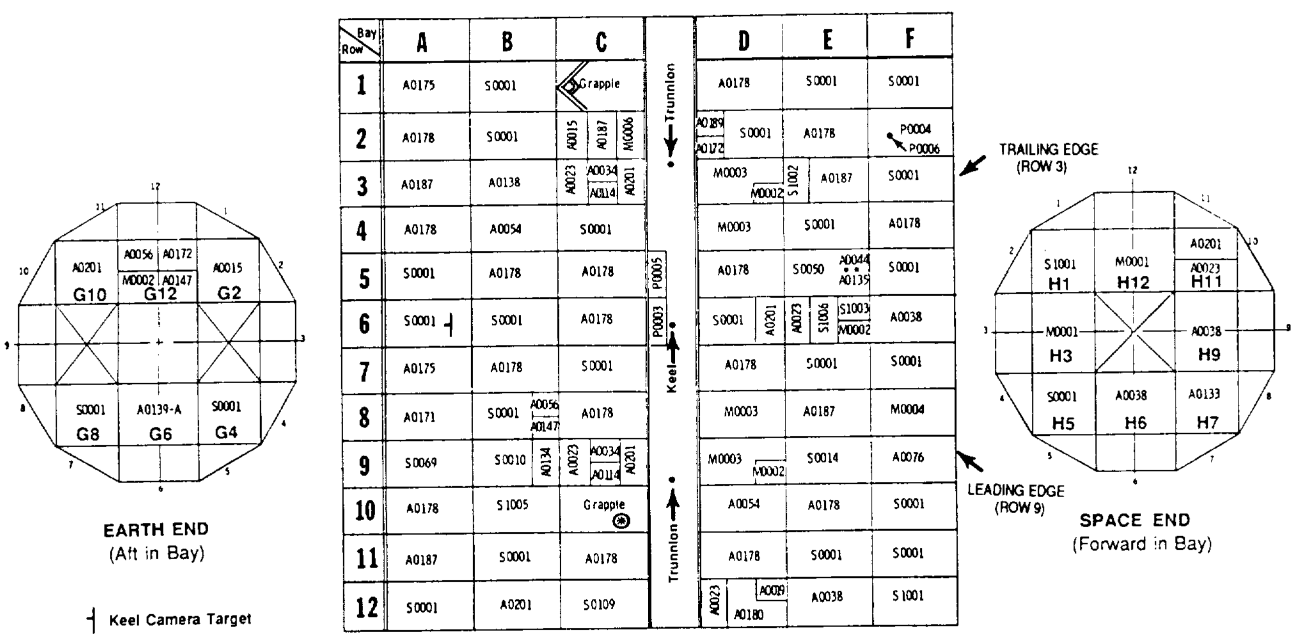


Figure 24.- Sketch showing experiment placement on LDEF.

Figure 25.- Liftoff of STS-41C. (Photo L-84-5648)

Figure 26.- LDEF immediately after deployment. (Photo L-84-04318)

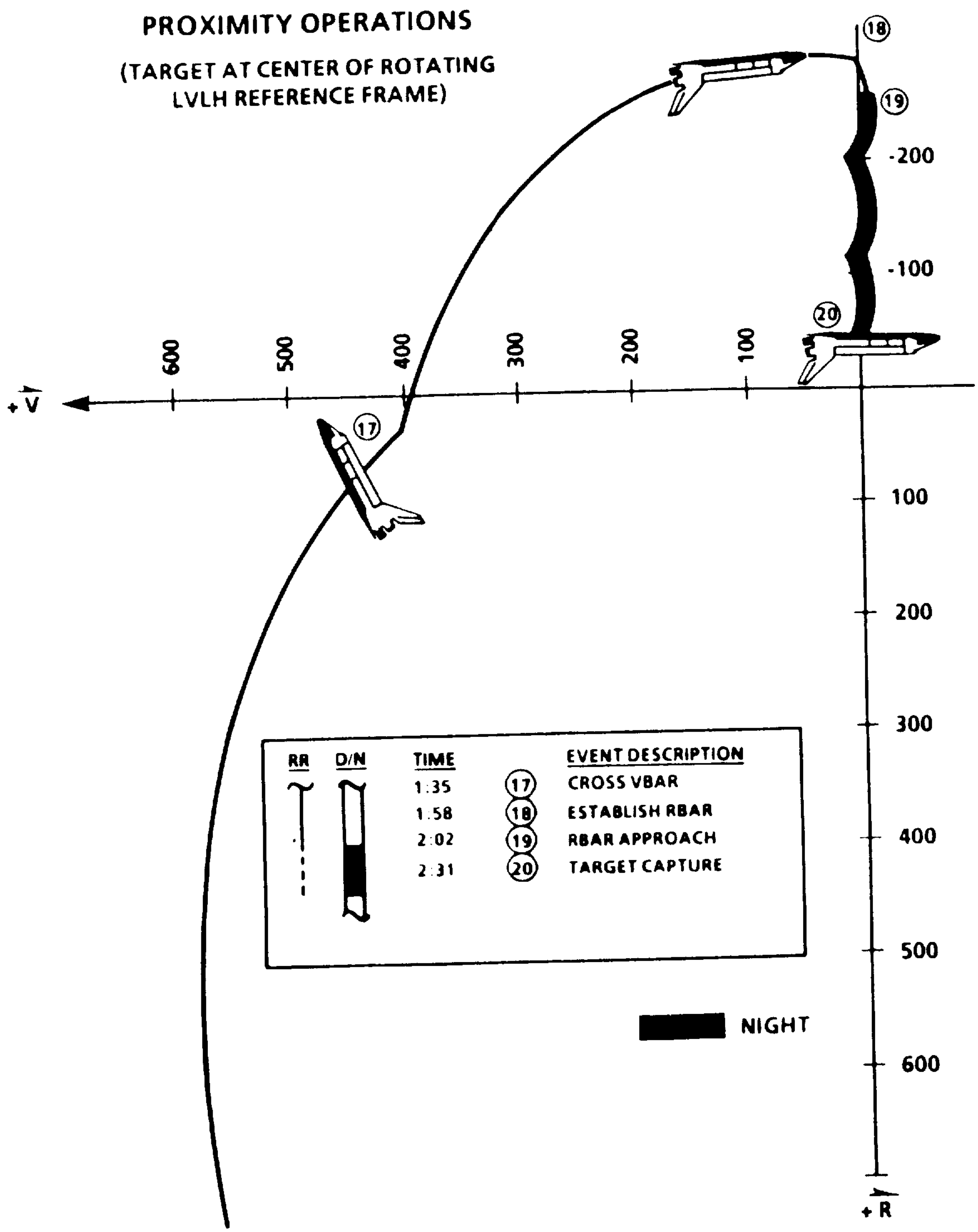


Figure 27.- Proximity operations for LDEF capture.

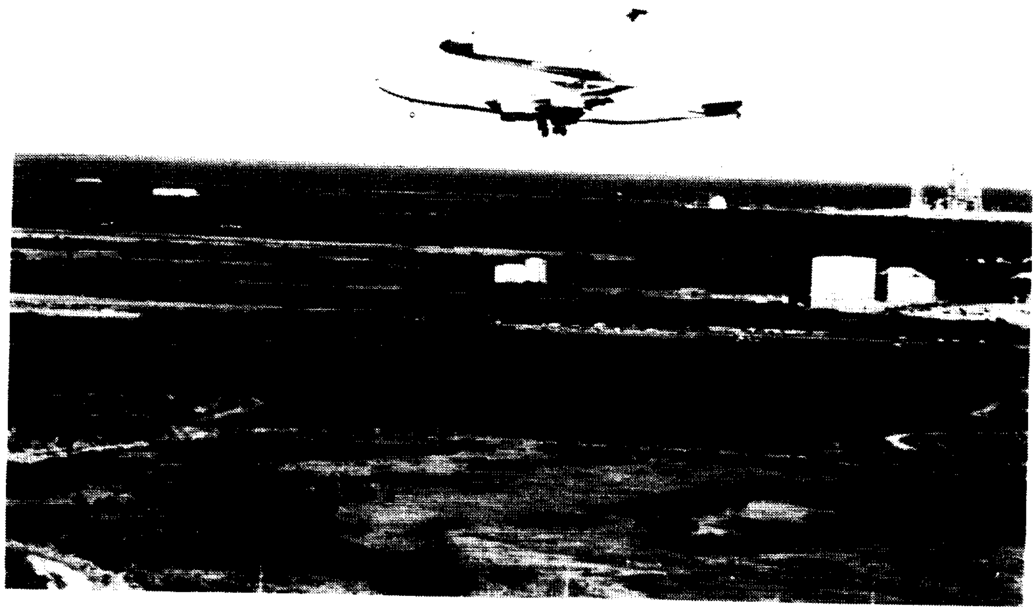


Figure 28.- Ferry aircraft prior to landing at KSC. (Photo L-90-10836)

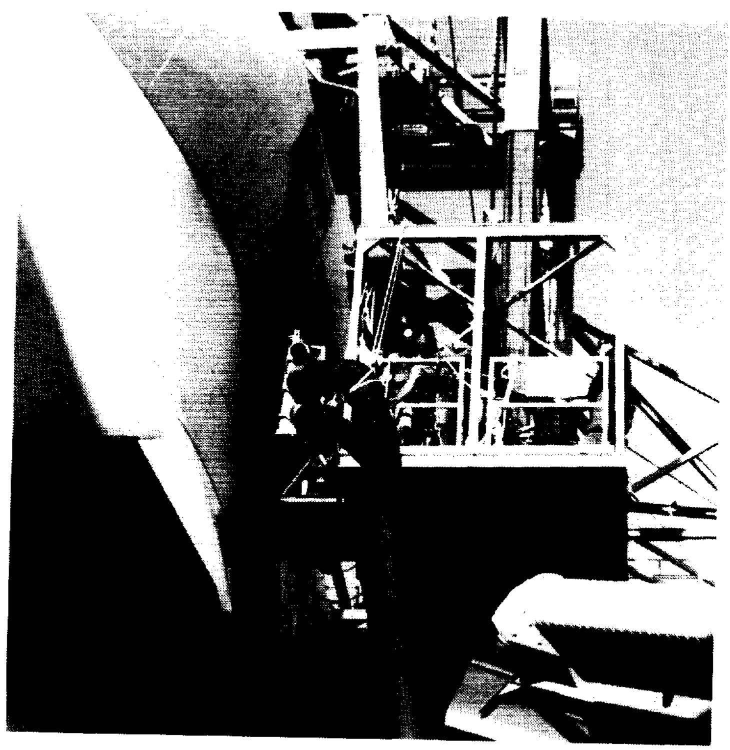


Figure 29.- Orbiter in Mate/Demate Facility. Payload bay purge lines being connected. (Photo KSC-390C-583.05)

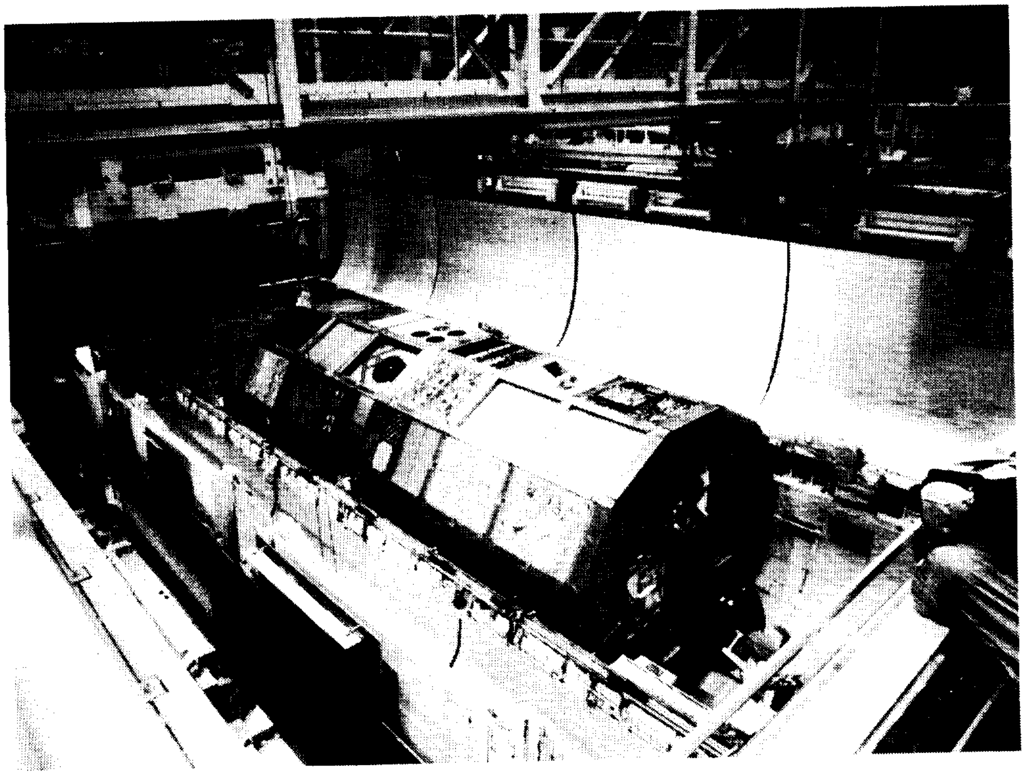


Figure 30.- Payload bay doors being opened in Orbiter Processing Facility. (Photo L- 90-01079)

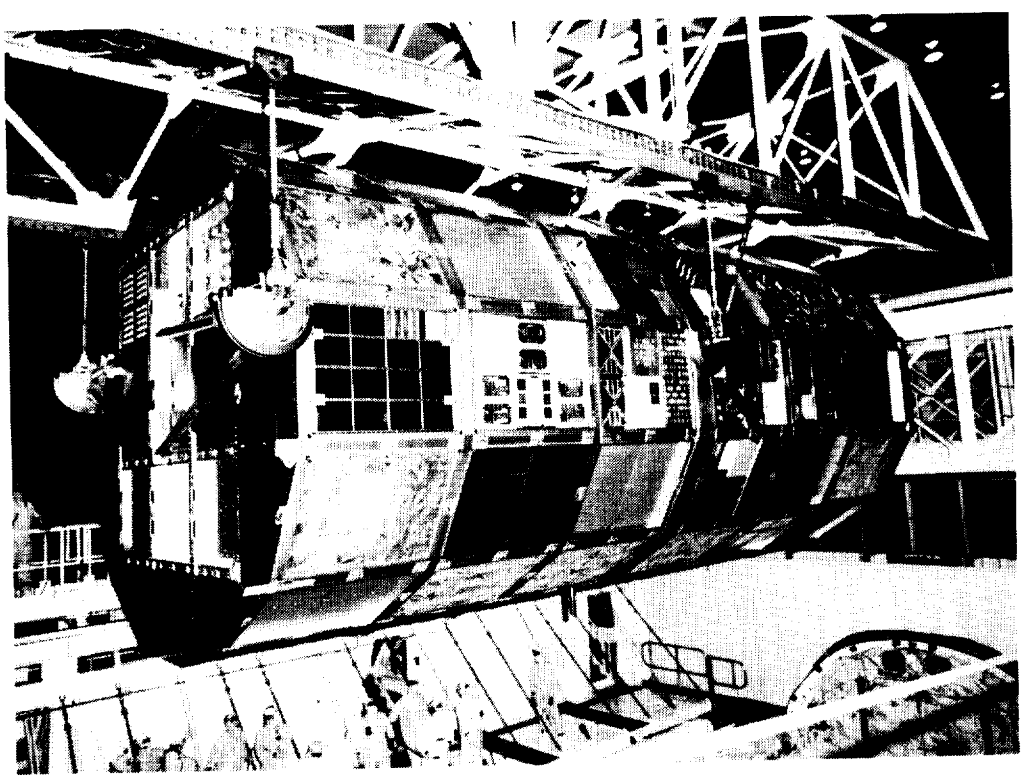


Figure 31.- LDEF being lifted from cargo bay. (Photo L-90-01087)

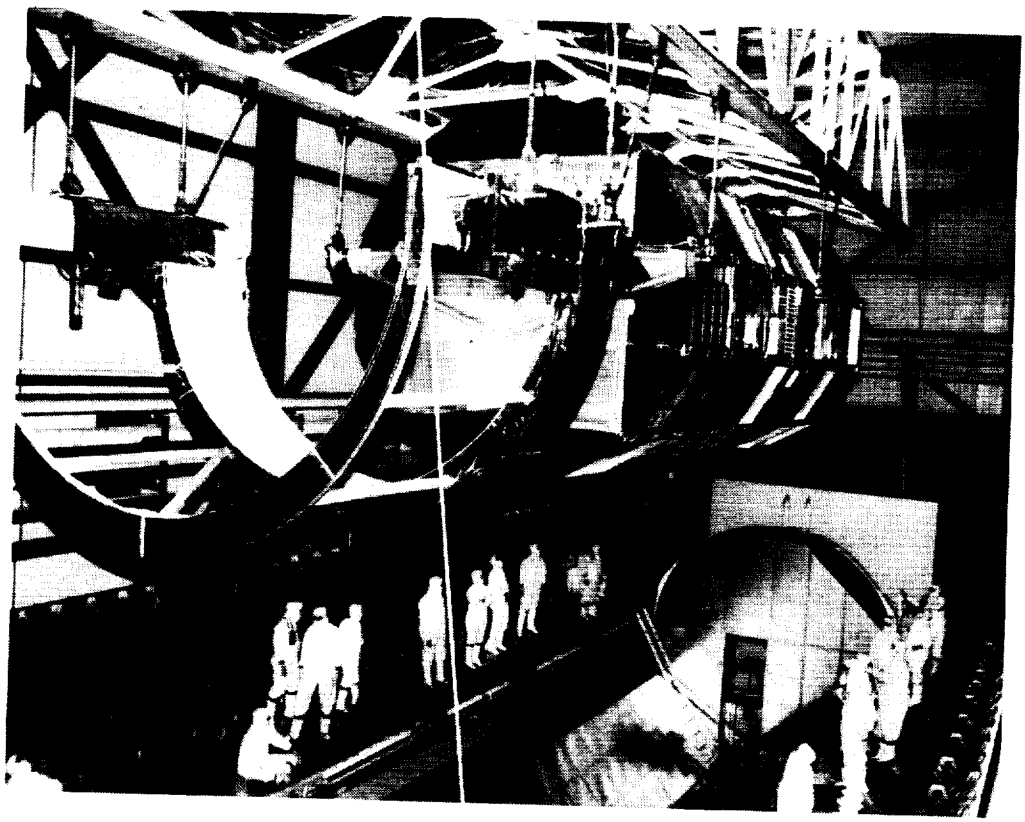


Figure 32.- LDEF being lowered into payload canister in Orbiter Processing Facility. (Photo KSC-390C-619.12

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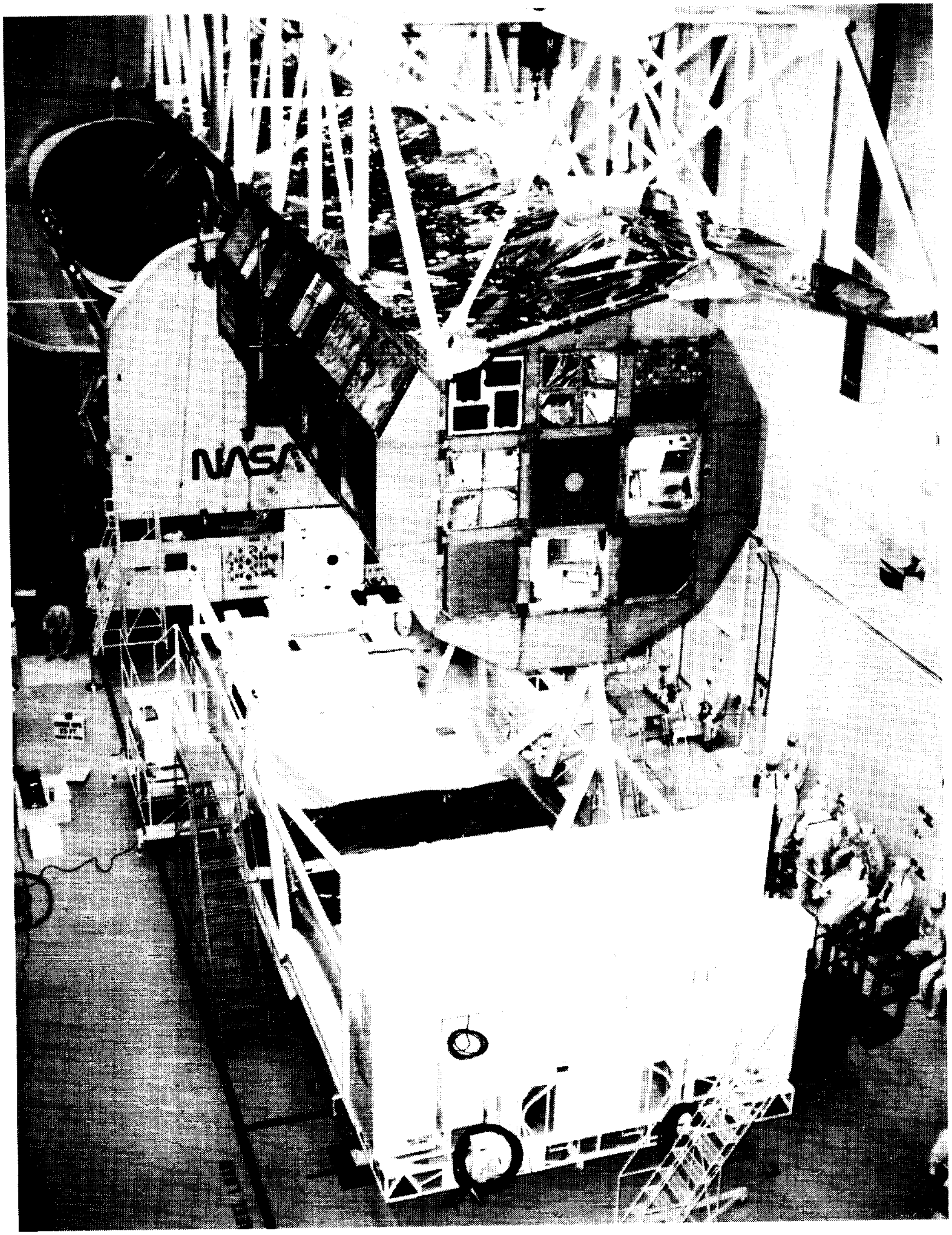

Figure 33.- LDEF being transferred from payload canister into LDEF Assembly and Transportation System in Operation and Checkout Building. (Photo L-90-1258)

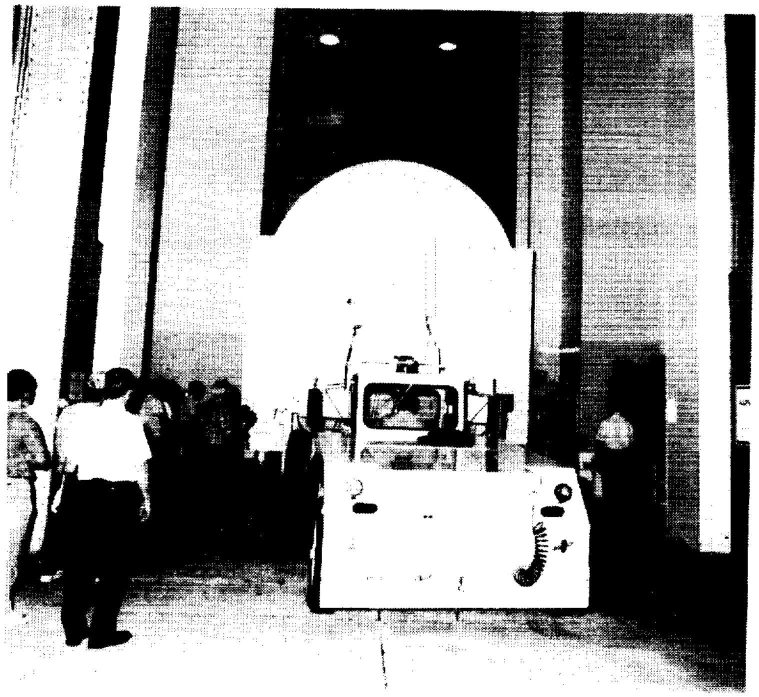

Figure 34.- Transfer of LDEF Assembly and Transportation System (LATS) into Spacecraft Assembly and Encapsulation Facility II (SAEF II) airlock. Note street clothes. (Photo L-90-01555)

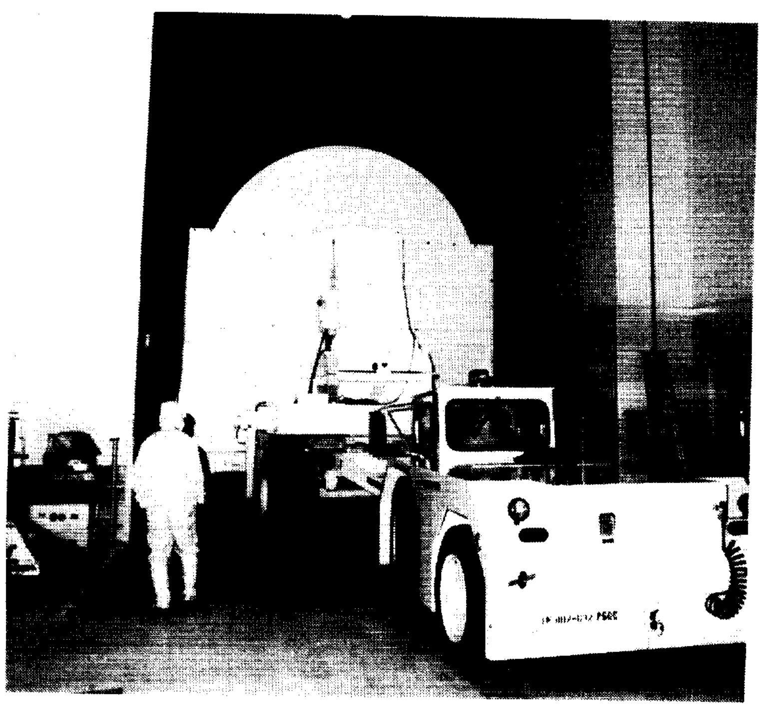

Figure 35.- Transfer of LDEF Assembly and Transportation System (LATS) from airlock into clean room of Spacecraft Assembly and Encapsulation Facility II. Note clean room clothing. (Photo L-90-01553)

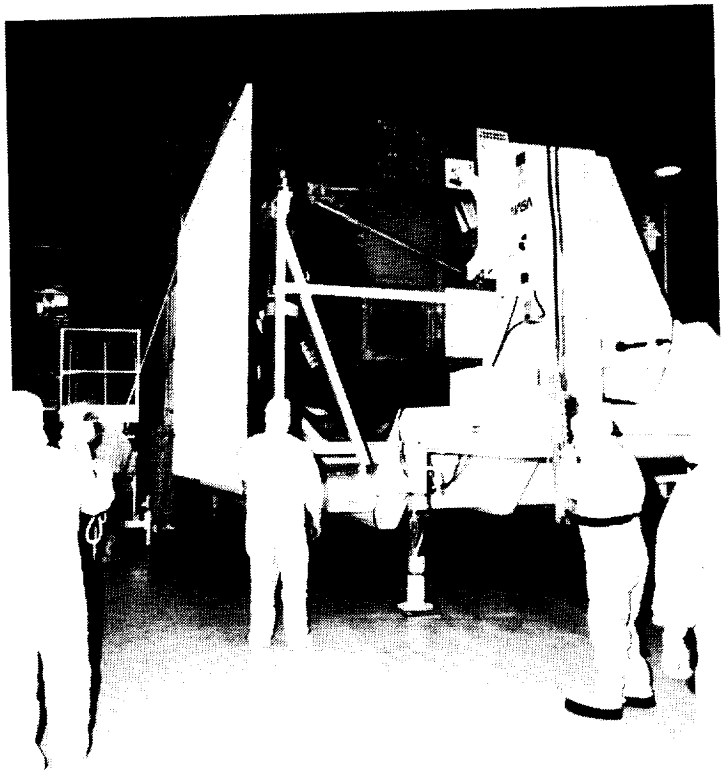

Figure 36.- LDEF Assembly and Transportation System (LATS) cover being removed in Spacecraft Assembly and Encapsulation Facility II (SAEF II). (Photo KSC-390C-2774.09)

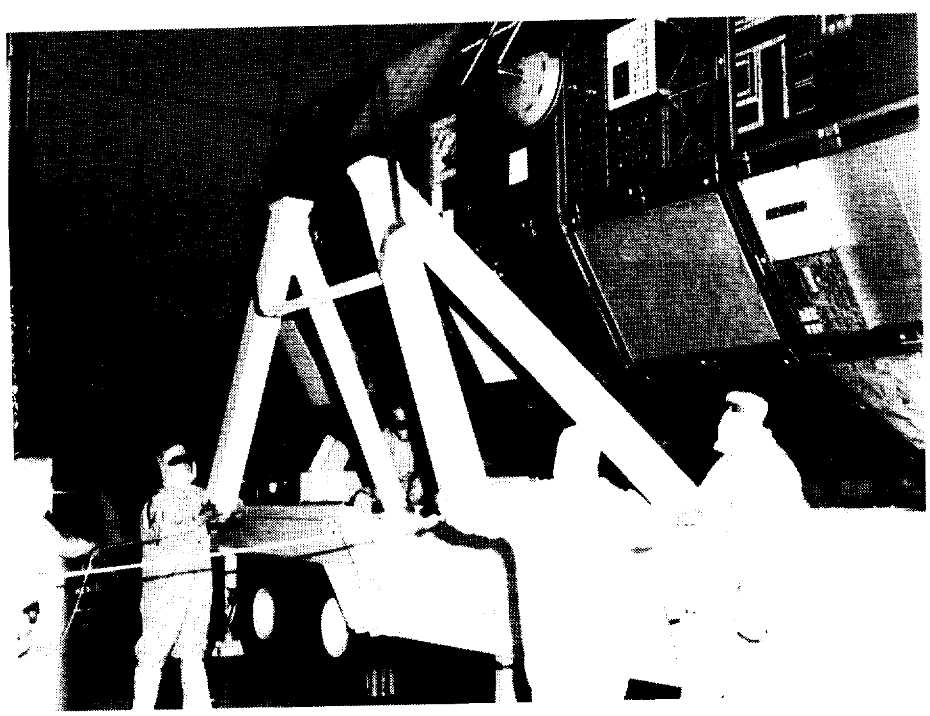

Figure 37.- LDEF Assembly and Transportation System (LATS) being configured for Spacecraft Assembly and Encapsulation Facility II (SAEF II) operations (Photo L-90-01728)

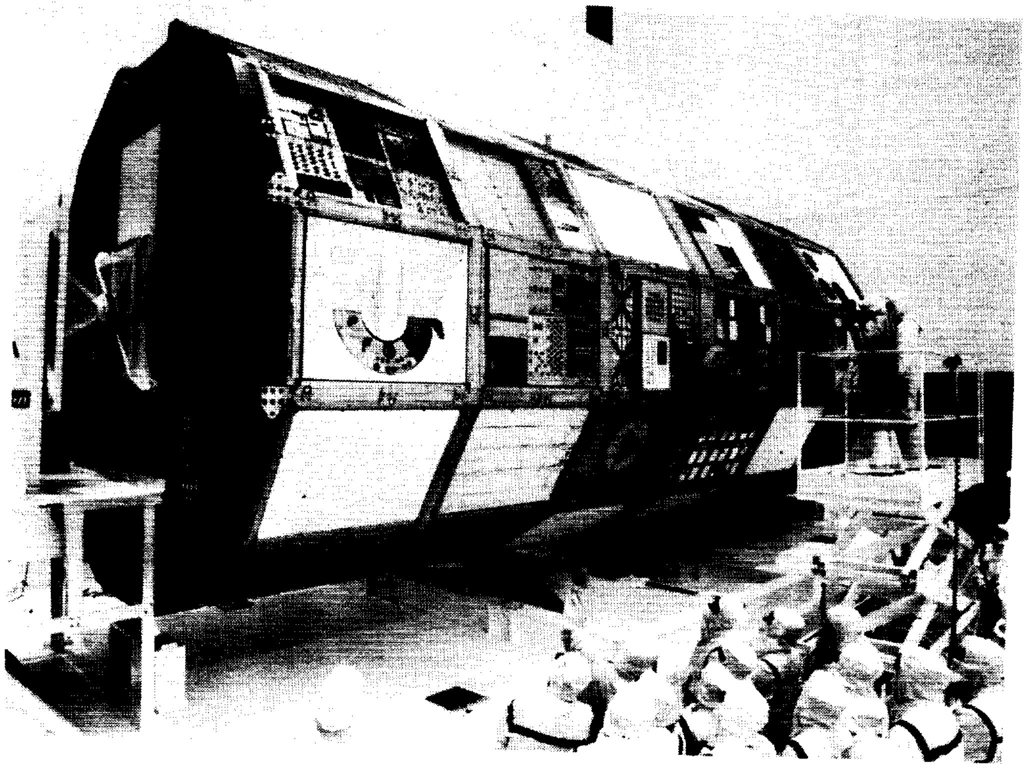

Figure 38.- Personnel inspection LDEF. (Photo L-90-02273)

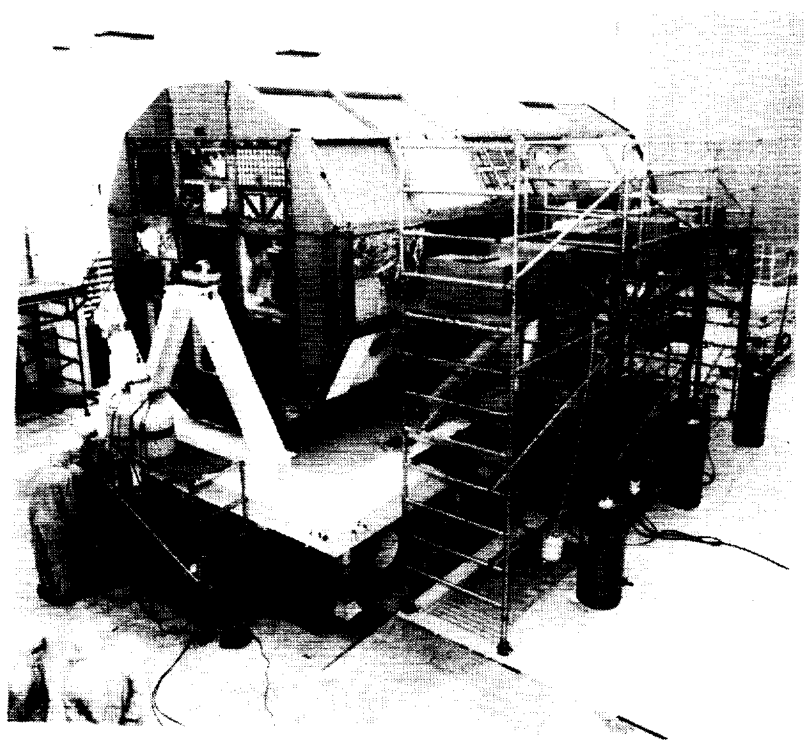

Figure 39.- Radiation measurements instrumentation setup. (Photo KSC-390C-760.07)

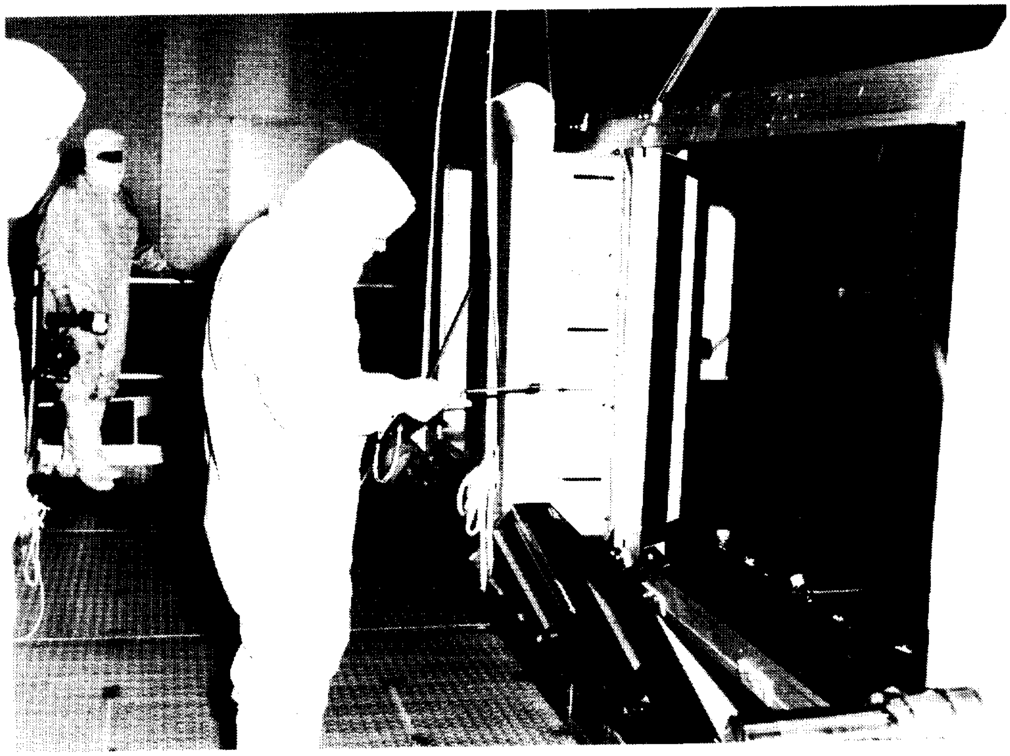

Figure 40.- Tray lifting fixture being attached to tray flange. (Photo L-90-03089)

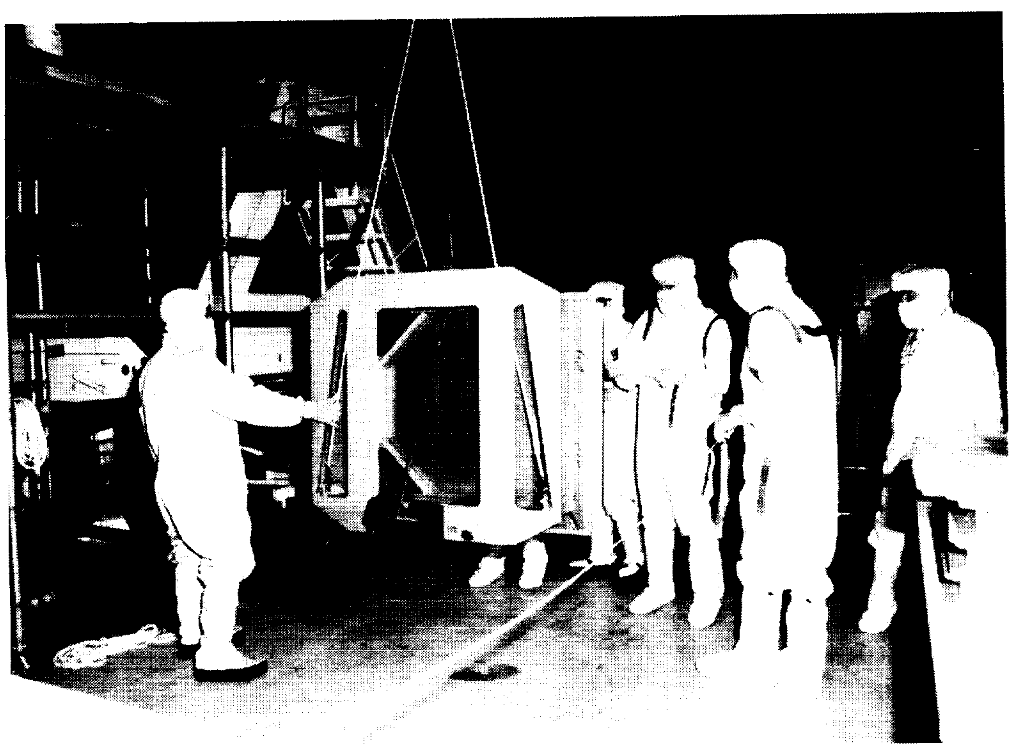

Figure 41.- Tray being inspected prior to being placed on rotator. (Photo L-90-03082)

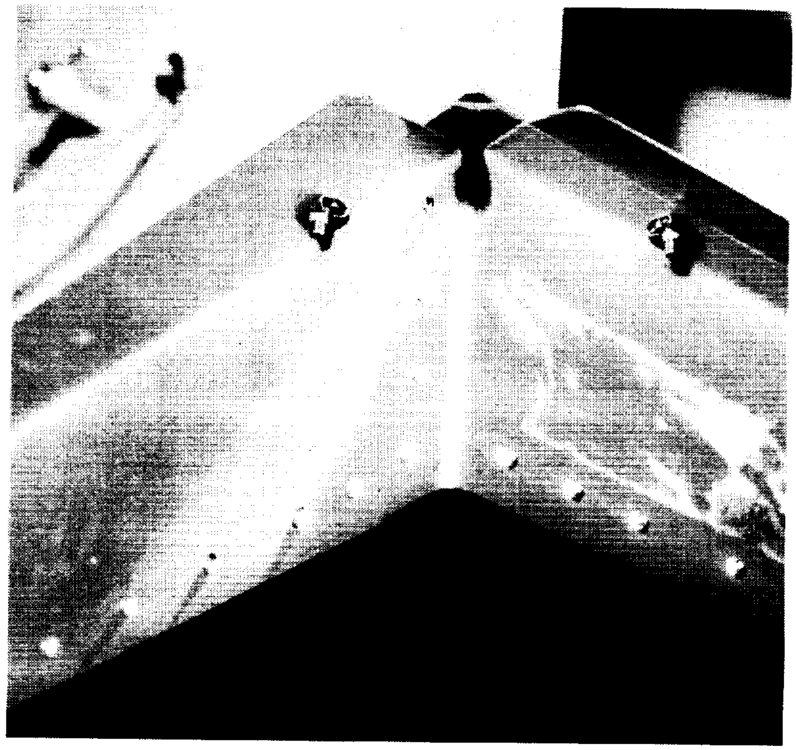

Figure 42.- Example of tray contamination. (Photo KSC-390C-1537.12)

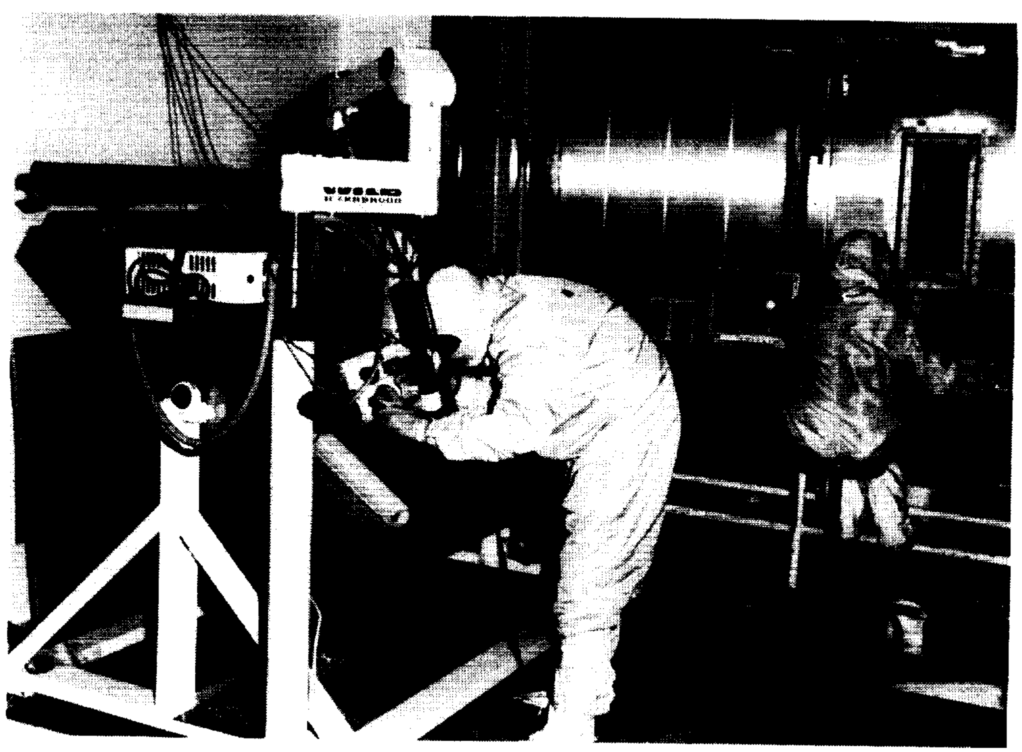

Figure 43.- Experiment being scanned for meteoroid and debris impacts. (Photo L- 90-03135)

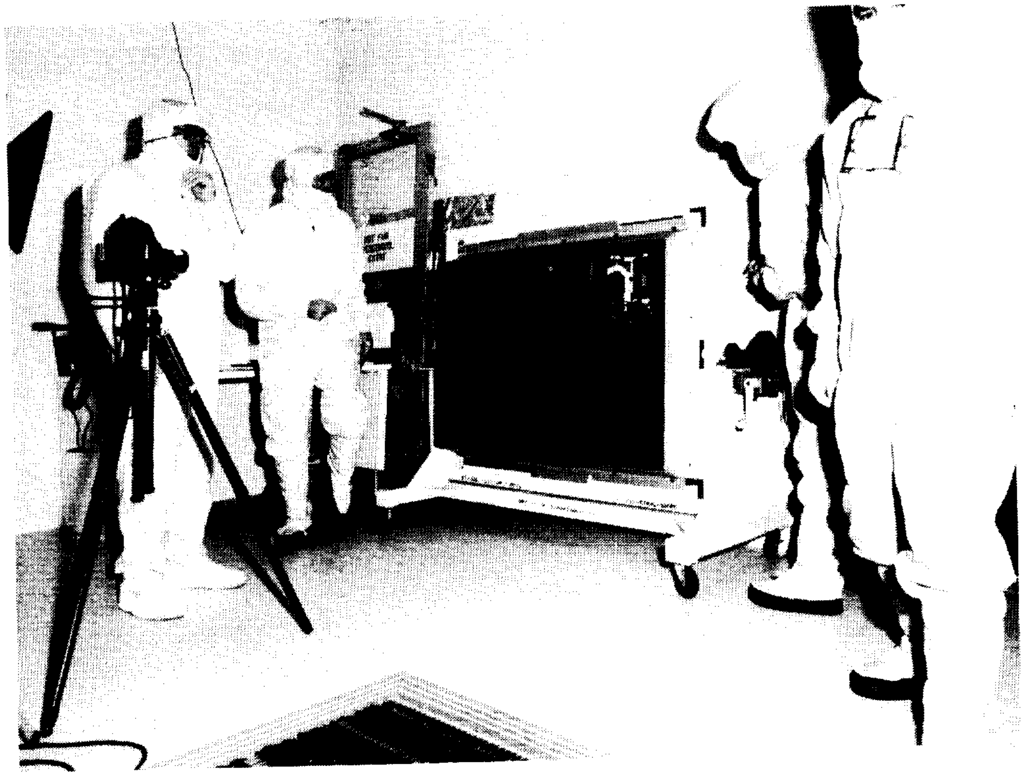

Figure 44.- Experiment tray set up for photo survey. (Photo L-90-03088)

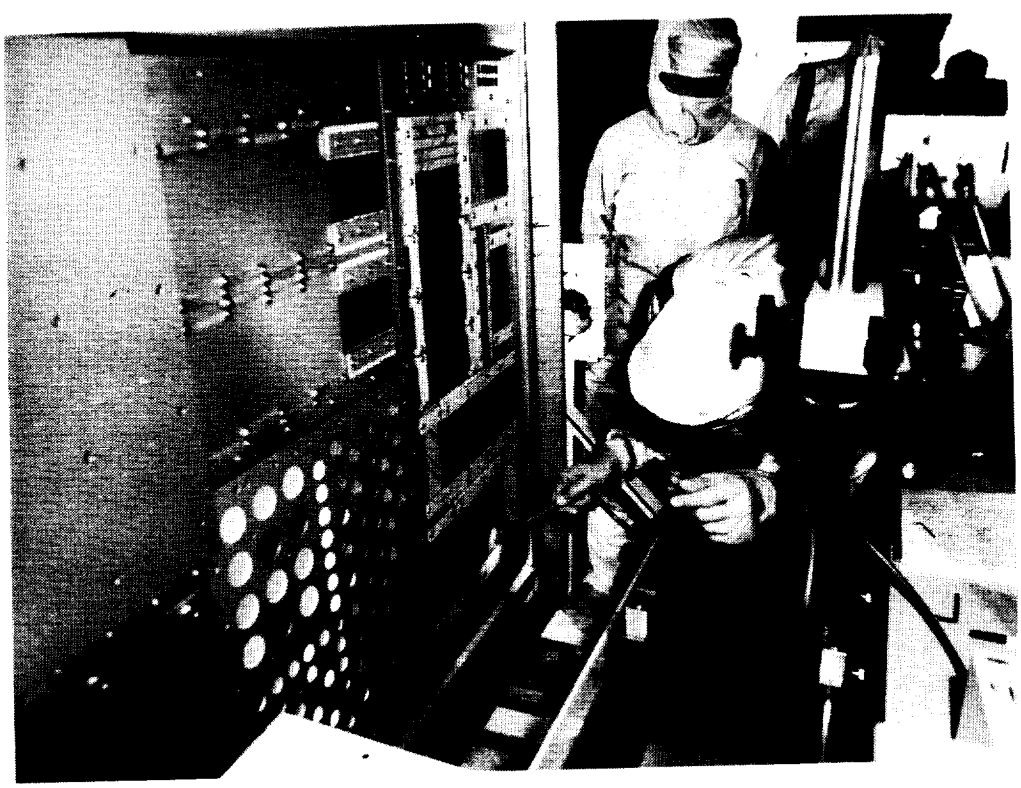

Figure 45.- Tray set up for contamination measurements. (Photo L-90-03033)

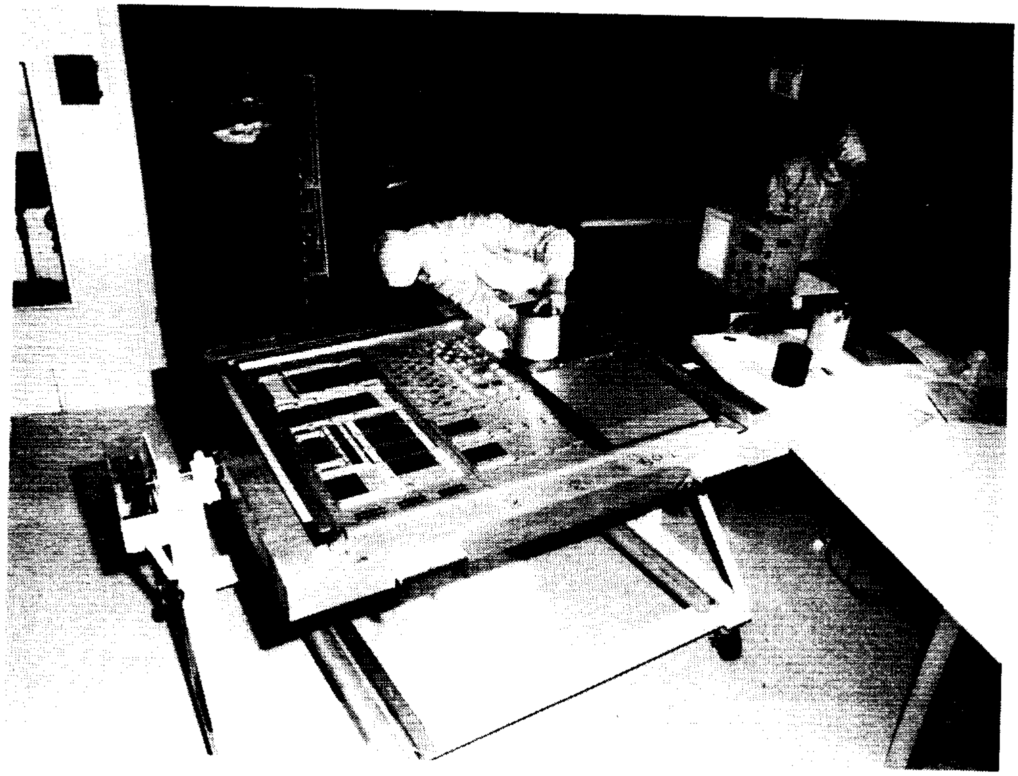

Figure 46.- Thermal properties measurements of experiment surfaces. (Photo L-90-03039)

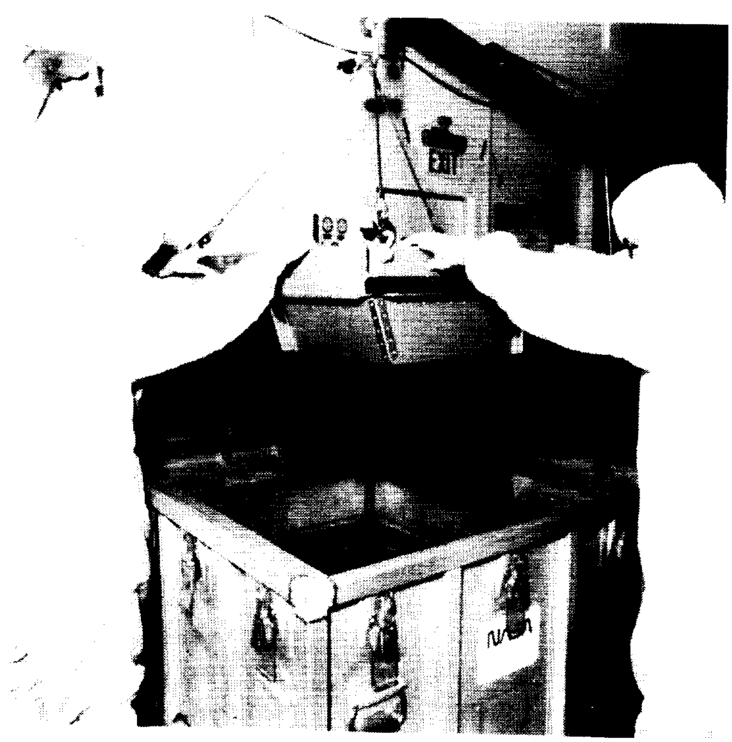

Figure 47.- Placement of experiment tray into shipping container. (Photo KSC-390C-1471.08)

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Figure 48.- Dye penetrant test on trunnion mounting holes in center ring structure.
(Photo KSC-390C-3768.08)

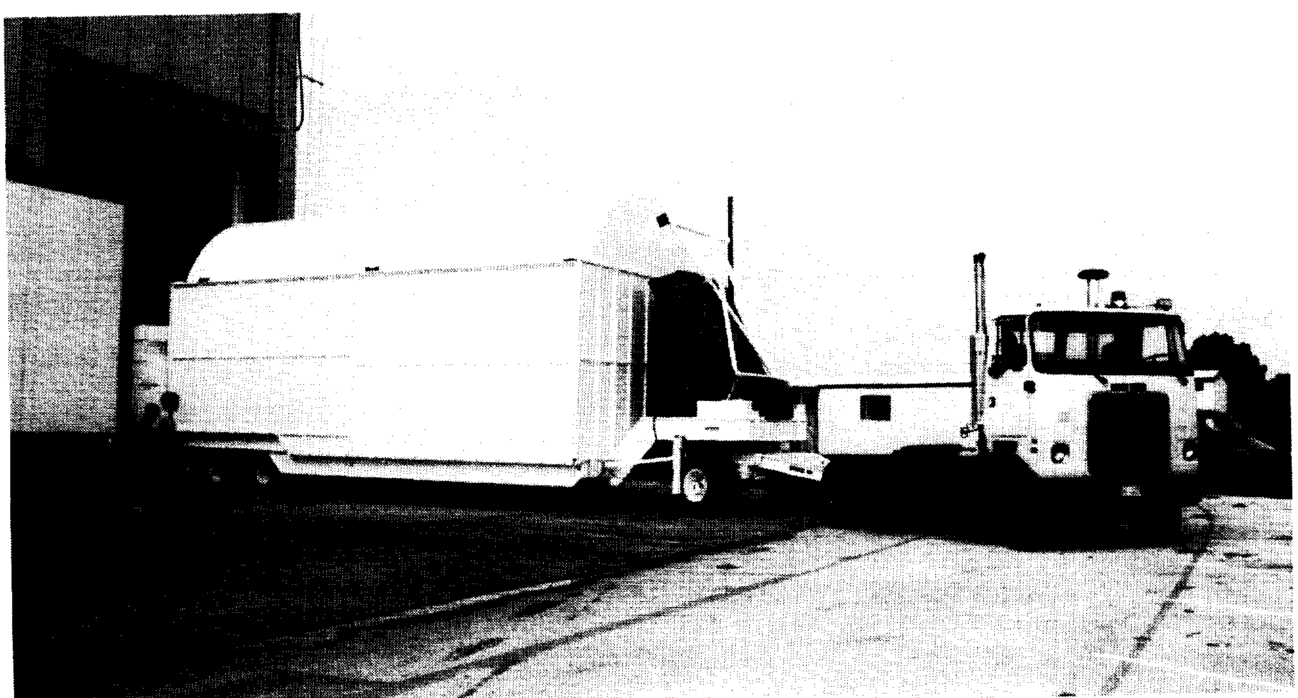

Figure 49.- LDEF Assembly and Transportation System (LATS) containing LDEF structure leaving Spacecraft Assembly and Encapsulation Facility II (SAEF II).
(Photo KSC-390C-3974.05)

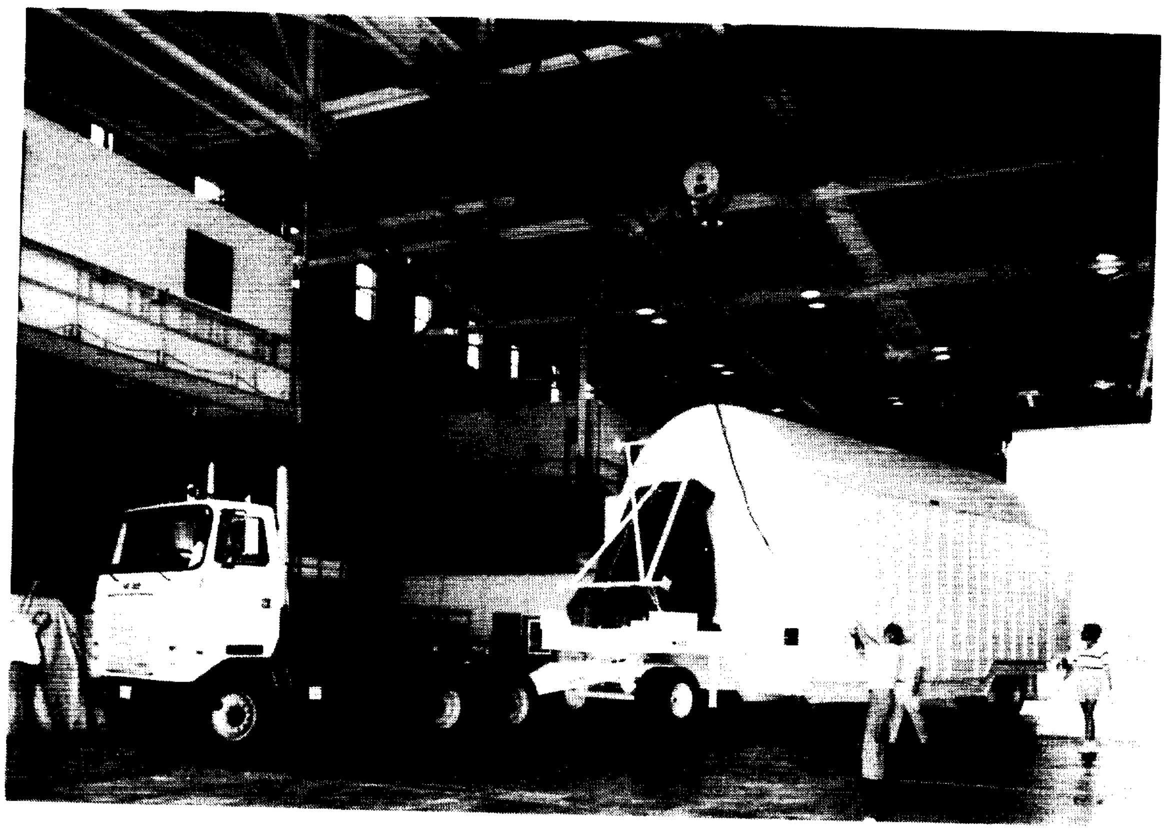

Figure 50.- LDEF Assembly and Transportation System (LATS) containing LDEF structure being placed in storage. (Photo KSC-390C-3976.11)